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Book of abstracts

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Partial quenching and chiral symmetry breaking

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Partially quenched chiral perturbation theory usually assumes that valence quarks propagating on gauge configurations prepared with sea quarks of different masses will form a chiral condensate as the valence quark mass goes to zero. I present a counterexample involving non-degenerate sea quarks where the valence condensate does not form.

Vacuum Structure and Confinement / 1

Instanton-dyons induce both the chiral symmetry breaking and confinement

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QCD topology -- mostly instantons -- had been used in the past to explain near-zero Dirac states and chiral symmetry breaking. At $T \sim T_c$ instanton are known to get
decomposed into N_c instanton-dyons. Several lattice observation were naturally
explained by instanton-dyons.
Their partition function is now numerically generated: the statistical ensemble is then used to get spectrum of Dirac eigenstates: that is found
to produce both chiral broken and restored (gapped) spectra, as a function of T and N_f. Another development is account for the back reaction, from dyons to holonomy potential. Somewhat unexpectedly, that was recently shown to induce a (quasi) confining phase transition, in which the Polyakov line jumps to zero value.

Application beyond QCD / 3

Spectrum and Observables in Yang-Mills-Higgs Theory

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The Higgs sector of the standard model, the Higgs and the W/Z bosons, is a quite peculiar theory. Because of the Higgs effect, in some cases the observable particles, i.e. gauge-invariant bound states, have the same mass as the elementary particles. This is what makes perturbation theory in the electroweak sector possible. Under which condition this holds true is not only important for understanding the Higgs sector itself, but may have severe implications for observable states in generic higgsed theories. The spectrum of observables and elementary particles, and thus the validity of a perturbative picture, is studied in a large area of the phase diagram of Yang-Mills-Higgs theory, starting from the QCD-like domain into the region of a potentially heavy Higgs. The results show that the low-lying spectrum depends on whether the theory is in a QCD-like region or a Higgs-like region, but the spectrum is otherwise rather inert to the microscopic details for a wide range of parameters. The applicability of a simple perturbative description is found to be restricted to only an intermediate range of 'Higgs' masses.

Hadron Structure / 4

A framework for the calculation of the $\Delta N\gamma^*$ transition form factor on the lattice

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Using the non-relativistic effective field theory framework in a finite volume, we discuss the extraction of the $\Delta N\gamma^*$ transition form factors from lattice data. A counterpart of the L\"uscher approach for the matrix elements of unstable states is formulated. In particular, we thoroughly discuss various kinematic settings, which are used in the calculation of the above matrix element on the lattice. The emerging L\"uscher-Lellouch factor and the analytic continuation of the matrix elements into the complex plane are also considered in detail. A full group-theoretical analysis of the problem is made, including the partial-wave mixing and projecting out the invariant form factors from data.

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Signal/noise optimization strategies for stochastically estimated correlation functions

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Numerical studies of quantum theories usually rely upon an accurate determination of stochastically estimated correlation functions in order to extract information about the spectrum of the theory and matrix elements of operators. The reliable determination of such correlators is often hampered by an exponential degradation of signal/noise at late time separations. I will demonstrate that it is sometimes possible to achieve significant enhancements of signal/noise by appropriately optimizing correlators with respect to the source and sink interpolating operators. The ideas will be demonstrated for both a toy model, and single hadron correlators in QCD.

Theoretical Developments / 7

Prepotential Formulation of Lattice Gauge theories

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Within the Hamiltonian formulation of Lattice gauge theories, prepotentials, belonging to the fundamental representation of the gauge group and defined locally at each site of the lattice, enables us to construct local loop operators and loop states. Within this prepotential approach one gets mass gap analytically in some approximations in the weak coupling limit of the theory.

Theoretical Developments / 8

Pion masses in 2-flavor QCD with $¥eta$ condensation

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We investigate some aspects of 2-flavor QCD with $m_u¥not= m_d$ at low-energy, using the leading order chiral perturbation theory including anomaly effects. While nothing special happens at $m_u=0$ for the fixed $m_d¥not=0$, the neutral pion mass becomes zero at two critical values of m_u, between which the neutral pion field
condenses, leading to a spontaneously CP broken phase, the so-called Dashen phase. We also show that the "topological susceptibility" in the ChPT diverges at these two critical points. We briefly discuss a possibility that $m_u=0$ can be defined by the vanishing the "topological susceptibility. We finally analyze the case of $m_u=m_d=m$ with $¥theta=¥pi$, which is equivalent to $m_u= - m_d=-m$ with $¥theta = 0$ by the chiral rotation. In this case, the $¥eta$ condensation occurs at small m, violating the CP symmetry spontaneously. Deep in the $¥eta$ condensation phase, three pions become Nambu-Goldstone bosons, but they show unorthodox behavior at
small m that $m_¥pi^2 = O(m^2)$, which, however, is shown to be consistent with the chiral Ward-Takahashi identities.

Nonzero temperature and Density / 9

Locating the critical end-point of QCD

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I will give an overview on our recent results for the phase
diagram of QCD with Nf=2+1 and Nf=2+1+1 flavors. We use a combination
of lattice and Dyson-Schwinger methods to determine the chiral
and deconfinement order parameters at finite temperature and chemical
potential. We find a critical end-point at large chemical potential
in the vicinity of the chiral critical line extrapolated from
lattice QCD.

Vacuum Structure and Confinement / 10

Study of axial magnetic effect

Mr. BRAGUTA, Victor [1]; Mr. CHERNODUB, Maxim [2]; Mr. GOY, Vladimir [3]; Mr. MOLOCHKOV, Alexander [3]; Mr. ULYBYSHEV, Maxim [4]; Mr. LANDSTEINER, Karl [5]

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The axial magnetic field, which couples to left- and right-handed fermions with opposite signs, may generate an equilibrium dissipationless energy flow of fermions in the direction of the field even in the presence of interactions. In this report numerical observation of the Axial Magnetic Effect in SU(2) lattice gauge theory is presented. The temperature behavior of the Axial Magnetic Effect is
studied. It is shown that in the confinement (hadron) phase the effect is absent. In the deconfinement transition region the conductivity quickly increases, reaching the asymptotic T^2 behavior in a deep deconfinement (quark-gluon plasma) phase.

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Status of the SU3 Lambda Scale

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We compare the non-perturbative SU(3) lambada scale of Necco and Sommer with the lambda scale derived by Bazavov et al. from deconfining phase transition data of the Bielefeld group and others. Though the relative discrepancy is never larger than 2%, it matters in some applications. Differences are encountered between results from the set of smaller lattices of Necco and Sommer and pseudo-deconfining temperatures on similarly sized lattices, while their set of less accurate calculations on larger lattices is consistent with either of the results from smaller lattices. In conclusion, more accurate calculations on large lattices are desirable.

Theoretical Developments / 12

The Hadronic Spectrum and Confined Phase in (1+1)-Dimensional Massive Yang-Mills Theory

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Massive Yang-Mills theory is known to be renormalizable in 1+1 dimensions. The gluon mass is introduced by coupling the gauge field to an SU(N) principal chiral nonlinear sigma model. The proof of renormalizability relies on the asymptotic freedom of the sigma model. However, renormalization forces the gluon mass to infinity. The continuum theory is in a confined phase rather than a Higgs phase. The physical excitations of the system are hadron-like bound states of sigma model particles. We calculate the massive spectrum of meson-like bound states analytically, using the exact S-matrix of the sigma model. The baryon-like spectrum can be found in principle by solving a quantum mechanical N-body problem. We remark on the evidence for the confined phase found for SU(2) in recent lattice simulations by Gongyo and Zwanziger. Their simulations show evidence for a Higgs-like phase which seems to disappear with increasing volume, finding agreement with our analysis in the continuum.

Vacuum Structure and Confinement / 13

Smearing Center Vortices

Mr. HOELLWIESER, Roman [1]; Prof. ENGELHARDT, Michael [1]

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We present a method to smear (center projected) Z(2) vortices in order to obtain properties of the original (full) SU(2) configurations. In particular we address the problem that Z(2) configurations cannot be treated with overlap (or chirally improved) fermions due to their lack of smoothness. We develop a method to regain this smoothness and simultaneously maintain the center vortex structure. We verify our method with various gluonic and fermionic observables.

Application beyond QCD / 14

Lattice path integrals for relativistic and non-relativistic many-body quantum systems

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New formulation of path integrals for relativistic quantum systems will discussed. Influence of the relativistic effects on the properties of quantum systems will be studied by means of the Monte Carlo method. A generalization of this approach to the case the path integral quantization of the Born-Infeld field theory will also discussed.

Theoretical Developments / 41

Fermion Mass Generation without a chiral condensate

Prof. CHANDRASEKHARAN, Shailesh [1]; Mr. AYYAR, Venkitesh [1]

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Massless fermions can become massive due to interactions through the mechanism of Spontaneous Symmetry Breaking (SSB). This mode of mass generation is popular and has been used in the Standard Model. Here, we explore
the possibility of fermions acquiring a mass through interactions, but without SSB.\\
We consider a fermion system on a cubical lattice and introduce an on-site four-fermion interaction with coupling constant U. Using the symmetries of the system on the lattice, we can predict
the existence of massless fermions for small $ U $. For very large values of $ U $, we can argue that the fermions become massive without the formation of a fermion bilinear condensate.
Monte Carlo results suggest that chiral condensate is zero for all values of the coupling constant. We show that the phase transition from the massless to the massive phase is second order. We also calculate
the critical exponents of the theory. The existence of a second order phase transition implies that one can take the continuum limit of the lattice model and obtain an interesting Quantum Field Theory with a new mechanism for fermion mass generation.

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Testing the Witten–Veneziano mechanism with the Yang–Mills gradient flow on the lattice

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We present a precise computation of the topological charge distribution in the SU(3) Yang–Mills theory. It is carried out on the lattice with high statistics Monte Carlo simulations by employing the clover discretization of the field strength tensor combined with the Yang–Mills gradient flow. The flow equations are integrated numerically by a fourth-order structure-preserving Runge–Kutta method. We have performed simulations at four lattice spacings and several lattice sizes to remove with confidence the systematic errors in the second (topological suceptibility χ) and the fourth cumulant of the distribution. In the continuum we obtain χ=185(5) MeV and the ratio between the fourth and the second cumulant R=0.233(45). Our results disfavour the θ-behaviour of the vacuum energy predicted by dilute instanton models, while they are compatible with the expectation from the large-N expansion.

Algorithms and Machines / 43

Dynamical QCD+QED simulation with staggered quarks

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Electromagnetic effects play an important role in many phenomena such as isospin symmetry breaking in the hadron spectrum, hadronic contributions to g-2, etc. We have generalized the MILC QCD code to include the electromagnetic field. In this work, we focus on simulations including charged sea quarks using the RHMC algorithm. We explain the algorithm, code performance, and results for some observables.

Physics beyond the standard model / 44

Models of Walking Technicolor on the Lattice

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We perform lattice simulations gauge theories with fermions in non-fundamental representations of the gauge group, which might be models for Walking Technicolor theories. In particular we update results reported earlier on SU(3) gauge theory with colour-sextet quarks. In addition we will report on results (if any) obtained for SU(2) gauge theory with colour-adjoint fermions.

Nonzero temperature and Density / 45

Deconfinement transition as a black hole formation by the condensation of QCD string

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In the gauge/gravity duality, the deconfinement transition in the gauge theory is identified with a formation of black hole in the dual gravity theory. In this talk, firstly we give quantitative evidence for this identification from the thermodynamic study of the supersymmetric theory. Then we consider generic gauge theories, including QCD, and show that the deconfinement transition is the condensation of very long and self-intersecting QCD strings, which is analogous to the formation of a black hole in string theory. We provide a concrete picture by using lattice gauge theory and matrix models in the Hamiltonian formulation,
and give numerical evidence supporting this interpretation. As a by-product we derive an analytic formula for the deconfinement temperature of the lattice gauge theory in the strong coupling limit.
We also argue how the fast thermalization of the QGP can be understood from this viewpoint.

This talk is based on the following work:

Hanada, Hyakutake, Ishiki and Nishimura, Science (2014)[arxiv:1311.5607].
Hanada, Maltz and Susskind, arxiv:1405.****[hep-th], to appear.
Berkowitz, Hanada, Hayden and Susskind, in progress.

Theoretical Developments / 46

Polyakov Loop Correlations at Large N

Prof. NEUBERGER, Herbert [1]

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The topic of the presentation is the two-point single-eigenvalue distribution correlation function of Polyakov loops in the confined phase of four dimensional SU(N) YM theory at large N.

Chiral Symmetry / 47

Phase Diagram of Wilson and Twisted Mass Fermions at finite isospin chemical potential

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A finite lattice spacing may have a crucial impact on the phase diagram of QCD. The existence of the Aoki phase for Wilson fermions underlines this point. Sharpe and Wu already showed that this kind of lattice artifacts carry over to finite twisted mass. The next task is the calculation of the phase diagram at finite chemical potential. I will present the phase diagram of Wilson fermions of two-flavor QCD at finite twist as well as at finite iso-spin chemical potential. Thereby the order parameters of the new phases are pointed out and the pion masses are presented.

Theoretical Developments / 48

Crank-Nicolson discretization scheme and lattice fermions

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It is well known that Crank-Nicolson discretization scheme is second order accurate in time. Its application in the case of the Dirac operator leads to a lattice theory with reduced doublers and broken parity. Adding a 3-space Wilson term one obtains a single fermion which is second order accurate in time. In the case of an imaginary term the doubler degeneracy is lifted and the ground state describes a single Weyl fermion.

Poster session - Board 25 / 50

Fermion-bags and a new origin for a fermion mass

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Recent developments have shown that the fermion bag approach is a powerful method to solve fermion lattice field theories using Monte Carlo methods. Some sign problems that had remained unsolved earlier can now be solved within this approach. In this work we argue that the fermion bag approach also gives new insight into the mechanism of fermion mass generation. We discuss how chiral condensates can form in most traditional four-fermion models involving staggered lattice fermions although symmetries forbid them. Interestingly, we also discover the existence of models where fermions acquire a mass although the chiral condensate remains zero. In these models fermion masses seem to arise purely due to dynamical reasons rather than due to spontaneous symmetry breaking.

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Solution to new sign problems with Hamiltonian Lattice Fermions

Ms. HUFFMAN, Emilie [1]; Prof. CHANDRASEKHARAN, Shailesh [1]

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We present a solution to the sign problem in a class of particle-hole symmetric Hamiltonian lattice fermion models on bipartite lattices using the idea of fermion bags. The solution remains valid when the particle hole symmetry is broken through a staggered chemical potential term. This solution allows, for the first time, simulations of some massless four-fermion models with minimal fermion doubling and with an odd number of fermion flavors using ultra-local actions. One can thus study a variety of quantum phase transitions that have remained unexplored so far due to sign problems.

Plenary / 52

Conference opening

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Hadron spectroscopy and interaction / 53

Excited isovector mesons using the stochastic LapH method

Prof. JUGE, Keisuke [1]; Dr. LENKNER, David [2]; Dr. JHANG, You-Cyuan [2]; Dr. WONG, Chik-Him [3]; Prof. MORNINGSTAR, Colin [2]; Dr. BULAVA, John [4]; FAHY, Brendan [2]

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The spectrum of excited isovector mesons is studied using a 32^3 x 256 anisotropic lattice with u,d quark masses set to give a pion mass near 240 MeV. Results in the bosonic isovector nonstrange symmetry channels of zero total momentum are presented using correlation matrices of unprecedented size. In addition to spatially-extended single meson operators, large numbers of two-meson operators are used, involving a wide variety of light isovector, isoscalar, and strange meson operators of varying relative momenta. All needed Wick contractions are efficiently evaluated using a stochastic method of treating the low-lying modes of quark propagation that exploits Laplacian Heaviside quark-field smearing. Level identification is discussed.

Theoretical Developments / 54

Spectrum of the staggered Wilson Dirac operator in quenched lattice QCD backgrounds

Mr. ZIELINSKI, Christian [1]; Prof. ADAMS, David H. [1]

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Results for the spectrum of the staggered Wilson Dirac operator in quenched backgrounds (beta = 5.8 and 6) are presented for a range of different lattice sizes up to 16^3 x 32. Significant improvement in the physical branch of the spectrum is observed for the larger lattices. The results are also compared with spectrum results for the usual Wilson Dirac operator in the same backgrounds.

Nonzero temperature and Density / 55

Deconfinement transition in two-flavour lattice QCD with dynamical overlap fermions in an external magnetic field

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We study the influence of an external magnetic field on the deconfinement transition in two-flavour lattice QCD
with physical quark charges. We use dynamical overlap fermions without any approximation such as fixed topology and
perform simulations on a 16^3×6 lattice and at a pion mass around 500 MeV.
The pion mass (as well as the lattice spacing) was determined in the independent runs on 12^3×24 lattices.
We consider two temperatures, one of which is close to the deconfinement transition and the other is above it.
Within our limited statistics the dependence of the Polyakov loop and chiral condensate
on the magnetic field supports the "inverse magnetic catalysis" scenario in which the transition
temperature decreases as the field strength grows.

Hadron Structure / 56

Hadron mass decomposition from Lattice QCD

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Based on the lattice simulation with overlap fermions on 2+1 DWF fermion configurations on the 24^3 x 64 lattice, we carry out the first lattice QCD calculation of the quark and glue contributions to pseudoscalar and vector mesons and the nucleon. The quark mass term contributes about 50% to the mass of the light pseudoscalar mesons; whereas, it is not important in the masses of light vector mesons and the nucleon. With the QCD Hamiltonian and the trace anomaly, the glue components are deduced. They play an important role in the mass of the light hadrons.

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Pi N Sigma Term and Scalar Form Factor from Overlap Fermion

Prof. LIU, Keh-Fei [1]; Dr. YANG, Yi-Bo [1]; Dr. GONG, Ming [2]; Mr. SUN, Mingyang [1]

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We report our calculation of the pi N sigma term and scalar form factor from the overlap fermion on 2+1 flavor domain wall fermion configurations on the 24^3 x 64 lattice at the sea quark mass which
corresponds to the pion mass at 330 MeV. The improvement of the nucleon propagator and the quark loop with low mode average will be discussed.

Physics beyond the standard model / 58

The bosonic side of composite dark matter

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One intriguing coincidence in cosmology is that the observed dark matter and baryonic densities are within a factor of 5 in magnitude. A natural explanation for such a coincidence is that the origin of the dark matter density is intimately related to the early universe processes that led to the baryon asymmetry. Many of these "asymmetric" dark matter scenarios favor a strongly coupled composite sector ala QCD, where neutral, long-lived composites can survive to be observed today, but still have charged constituents to interact with early universe baryogenesis.
As a result, these neutral composites are expected to interact with ordinary matter through Higgs exchange or higher dimensional electromagnetic interactions such as magnetic moments, charge radii, and polarizabilties; the last of which cannot be avoided and can provide a lower bound for these theories. In this talk, I will discuss a theory of bosonic baryons in SU(4) gauge theory that only interact via Higgs exchange and polarizabilities. In particular, I will focus on the spectrum and Higgs exchange properties, whose interaction strength can vary based on ratios of the chiral to vector-like mass couplings. These calculations provide the foundation for future calculations of polarizabilities, which will ultimately bound this class of composite dark matter.

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Vacuum alignment and lattice artifacts

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When a subgroup of the flavor symmetry group of a gauge theory is weakly coupled to additional gauge fields, the vacuum tends to align such that the gauged subgroup is unbroken. At the same time, the lattice discretization typically breaks the flavor symmetry explicitly, and can give rise to new lattice-artifact phases with spontaneously broken symmetries. We discuss the interplay of these two phenomena, using chiral lagrangian techniques. Our main example is two-flavor Wilson QCD coupled to electromagnetism. We will briefly touch on theories with staggered fermions and composite Higgs models as well.

Nonzero temperature and Density / 60

Quark number density at imaginary chemical potential and its extrapolation to large real chemical potential by the effective model

Mr. TAKAHASHI, Junichi [1]; Mr. SUGANO, Junpei [1]; Mr. ISHII, Masahiro [1]; Prof. KOUNO, Hiroaki [2]; Prof. YAHIRO, Masanobu [1]

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We evaluate quark number densities at imaginary chemical potential by doing lattice QCD calculations on an 8^2*16*4 lattice with clover-improved Wilson quarks of two flavors. The quark number densities are extrapolated to the small real chemical potential region by assuming some function forms. The extrapolated quark number densities are consistent with those calculated at real chemical potential directly with the Taylor expansion method for the reweighing factors. Further extrapolation is also made to the large real chemical potential with the two-phase model consisting of the Walecka model for the hadron phase and the entanglement-PNJL model for the quark phase. The Walecka model is constructed to reproduce nuclear saturation properties, while the entanglement-PNJL model well account for temperature dependence of two-flavor lattice data for the order parameters such as the Polyakov loop, the thermodynamic quantities and the screening masses. Finally, we explore the hadron-quark phase transition with the two-phase model in the entire region of QCD phase diagram and discuss whether the phase diagram is consistent with two-solar mass observation of neutron stars.

Physics beyond the standard model / 61

The continuum limit of lattice N=4 super-Yang-Mills

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We know from previous studies that the symetries of the twisted Q-symmetric lattice theory are particularly powerful in terms of protecting the long distance effective theory from unwanted renormalizations. Here, it will be shown that rescalings of the lattice fields imply that only two fine-tunings are required, so that the N=4 theory is on a similar footing to clover fermions in lattice QCD. We also provide a blocking scheme that preserves the symmetries. We discuss this in relation to our recent result that restoring any of the discrete R symmetries is sufficient to obtain the correct continuum limit. An early numerical study of this issue is discussed. We conclude with prospects for a Monte Carlo renormalization group involving our blocking scheme.

Hadron Structure / 62

Precision calculations of nucleon charges g_A, g_S and g_T

Dr. GUPTA, Rajan [1]; Dr. LIN, Huey-Wen [2]; Dr. YOON, Boram [1]; Dr. BHATTACHARYA, Tanmoy [1]; Dr. COHEN, Saul [2]; Dr. JOSEPH, Anosh [3]

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This talk will present an update on the calculation of iso-vector nucleon charges g_A, g_S and g_T by the PNDME collaboration. The calculations are being done using clover valence quarks on 2+1+1 flavor HISQ lattices generated by the MILC collaboration at multiple values of the lattice spacing, light quark masses and lattice volumes. To extrapolate in the lattice volume, lattice spacing and quark mass, we make simultaneous fits to the data in these three variables and discuss the associated systematic uncertainty in the three charges. Lastly, we will examine how well these estimates, combined with precision measurements of neutron decays, can bound novel scalar and tensor interactions at the TeV scale.

Physics beyond the standard model / 63

Non-renormalization theorem and cyclic Leibniz rule in lattice supersymmetry

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We propose a lattice model of a complex SUSY quantum mechanics which realizes the non-renormalization theorem on lattice. In our lattice model, the Leibniz rule in the continuum, which cannot hold on lattice due to a no-go theorem, is replaced by the cyclic Leibniz rule (CLR) for difference operators. It is shown that the CLR allows two of four supercharges of the continuum theory to preserve while a naive lattice model can realize one supercharge at the most. A striking feature of our lattice model is that there are no quantum corrections to potential terms in any order of perturbation theory. This is one of characteristic properties of SUSY theory in the continuum. It turns out that the CLR plays a crucial role in the proof of the non-renormalization theorem. This result suggests that the CLR grasps an essence of supersymmetry on lattice.

Nonzero temperature and Density / 64

Effective Polyakov line actions, and their solutions at finite chemical potential

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I explain the “relative weights” strategy for deriving effective Polyakov line actions, at finite chemical potentials, from the underlying lattice gauge theories. Gauge-Higgs and heavy quark models are the examples considered. The effective Polyakov line theories still have a severe sign problem, and I compare results obtained using mean field and complex Langevin methods to solve such theories.

Nonzero temperature and Density / 65

Thermodynamics in the fixed scale approach with the shifted boundary conditions

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The fixed scale approach has various advantages to calculate the QCD equation of state on lattices. In this approach a series of temperatures are realized with single coupling parameters. Therefore zero temperature subtractions are common, and conditions for the line of constant physics are automatically satisfied. We test the fixed scale approach to study thermodynamics of SU(3) gauge theory using the shifted boundary conditions, which can largely increase the number of possible temperatures while keeping the advantages of the fixed scale approach. The simulations are performed with 32^3 x Nt lattices at beta=6.0. Calculations at 80 temperature are investigated with the single coupling parameter by using various boundary shifts at Nt=4,5,6,7,8 lattices. We present the results of the trace anomaly, and the transition temperature determined by the plaquette susceptibility. We also found that the boundary condition reduces lattice artifacts in the equation of state numerically.

Nonzero temperature and Density / 66

Curvature of the QCD critical line with 2+1 HISQ fermions

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We present results on the curvature of the critical line of QCD with 2+1 HISQ fermions at nonzero temperature and quark density obtained by analytic continuation from imaginary chemical potentials. Monte Carlo simulations are performed by means of the MILC code suitably modified to include a nonzero imaginary baryon chemical potential. We set the chemical potential at the same value for the three quark species, and we work on a line of constant physics with a light to strange mass ratio of 1/20.

Algorithms and Machines / 67

Multigrid Preconditioning for the Overlap Operator

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The overlap lattice discretization of the Dirac operator preserves the important physical property of chiral symmetry, at the expense of requiring much more effort when solving systems with this operator. We present a preconditioning technique based on another lattice discretization, the Wilson-Dirac operator. Recently, close to normal operators have gained popularity in numerical simulations. Therefore, we give a mathematical analysis which shows that our preconditioner is effective in an idealized setting where operators are assumed to be normal. This is then confirmed by numerical experiments which are performed for large lattice configurations coming from state-of-the-art physical simulations, implemented on a parallel cluster computer with up to 8,192 cores.

Physics beyond the standard model / 68

Calculating the chiral condensate diagrammatically at strong coupling

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We develop a diagrammatic approach for calculating the chiral condensate on the lattice at strong coupling for QCD and related theories with fermions in the symmetric, antisymmetric, and adjoint representations. The approach is inspired by recent work of Tomboulis and earlier work in which the chiral condensate is obtained diagrammatically in the limit of infinite coupling. We calculate the chiral condensate in this limit as a function of the number of colours and fermion flavours and discuss convergence of the approach and sources of error.

Hadron spectroscopy and interaction / 69

Scalar Mesons on the Lattice Using Stochastic Sources on GPU Architecture.

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We describe our studies of multi-pion correlation functions computed using stochastic propagators in quenched lattice QCD, harnessing GPUs for acceleration. We find that projecting onto momentum states for the pions becomes enormously expensive and has a poor scaling with the linear extent of the lattice. It is also found that correlations between stochastic propagators appearing in the same diagram, when a single set of random source vectors is used, lead to much larger errors than if separate random sources are used for each propagator.

We use L¨uscher's method and look for the σ in the $\pi\pi \rightarrow \pi\pi$ channel. The result is that multi-pion correlation functions must be considered, which inevitably involve all-to-all propagators, which are quite expensive and require many inversions. For this reason, GPUs are ideally suited to accelerating the calculation. For this work we have integrated the Columbia Physics System (CPS) and QUDA GPU inversion library, in the case of clover fermions.

We describe some other challenges that we have uncovered, in particular getting hit with Amdahl's law for the tying together and tracing of propagators in our calculations, as well as momentum projections. We have also accelerated these parts of our calculation using GPUs and show some benchmarks.

Hadron spectroscopy and interaction / 70

Pion-pion scattering phase shifts with the stochastic LapH method

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Progress in calculating scattering phase shifts on Nf=2+1 anisotropic clover Wilson lattices is described. The stochastic LapH method facilitates computations in large volumes and for light pion masses. Results for pion masses down to 250 MeV, keeping m_pi L > 4, are presented.

Physics beyond the standard model / 71

Simulating N=4 Super Yang-Mills

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N=4 Yang-Mills may be formulated on the lattice in such a way as to
preserve one exact supersymmetry. This has remarkable consequences;
the beta function of the lattice theory vanishes at one loop, the moduli space of the theory survives to all orders of perturbation theory and a maximum of two fine tunings are required to take the continuum limit.

I will review the formulation and describe the resulting phase diagram of the theory.
In certain parts of the phase
diagram a lattice monopole phase is found whose existence is driven
by the U(1)
sector of the theory. I show how
this lattice artifact phase can be avoided by the addition of a new term to
the lattice action which enforces an approximate projection from a U(N) to an
SU(N) gauge group. With the inclusion of this term simulations can be conducted at arbitrarily
large 't Hooft coupling.

Hadron spectroscopy and interaction / 72

DK and D* K scattering near threshold

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We study the three D_s quantum channels J^P = 0^+, 1^+ and 2^+ where experiments have identified the charm-strange states D*_s0 (2317), D_s1(2460), D_s1(2536) near the DK and D*K thresholds, and D*_s2(2573). We consider correlation functions for sets of qbar q operators and, for J^P = 0^+, 1^+, also the DK and D*K meson-meson interpolators and determine for these cases values of the elastic scattering amplitude. Constructing the full set of correlators requires propagators which connect any pair of lattice sites. For one ensemble of gauge configurations (32^3 x 64, m_pi= 156 MeV) a stochastic distillation variant is employed and for another ensemble (16^3 x 32, m_pi= 266 MeV) we use the full distillation method. Both, D*_s0(2317) and D_s1(2460), are found as bound states below threshold, whereas D_s1(2536), and D*_s2(2573) are identified as narrow resonances close to the experimental masses.

Plenary / 73

Hadron Structure

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Plenary / 74

Heavy Flavors

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Plenary / 75

Recent results on topology on the lattice (in memory of Pierre van Baal)

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Plenary / 76

Finite Temperature (\mu=0)

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Plenary / 77

K/pi physics

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Plenary / 78

Validity of ChPT -- is M_\pi=135MeV small enough ?

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Plenary / 79

Wilson flow and renormalization

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Plenary / 80

Wilson Award

Plenary / 81

Hadronic Interaction

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Plenary / 82

Simulation in Astrophysics

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Plenary / 83

Beyond the Standard Model

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Plenary / 84

New algorithms for finite density QCD

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Plenary / 85

Inclusion of isospin breaking effects in lattice simulations

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Plenary / 86

Quark masses

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Plenary / 87

Hadron Spectroscopy

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Plenary / 88

Multigrid for Lattice QCD

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Plenary / 89

FNAL E989 and g-2

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Plenary / 90

Hidden exact symmetry in graphene

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The emergence of massless Dirac fermion in graphene has attracted attention in recent years due to the remarkable features. The tight-binding honeycomb lattice hamiltonian to explain this feature has a close analogy with "the staggered fermion" which is widely used in lattice gauge theory. Employing the position space formalism developed in lattice gauge theory, we reformulate the tight-binding honeycomb model. We show that there exists a hidden exact symmetry at finite lattice spacing, which protects the masslessness of the Dirac fermion.

Plenary / 92

Lattice QCD with purely imaginary sources at zero and non-zero temperature.

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Plenary / 93

Few-body physics

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Few-body hadronic observables play an essential role in a wide number of processes relevant for both particle and nuclear physics. In order for Lattice QCD to offer insight into the interpretation of few-body states, a theoretical infrastructure must be developed to map Euclidean-time correlation functions to the desired Minkowski-time few-body observables. In this talk, I will first review the formal challenges associated with the studies of such systems via Lattice QCD, as first introduced by Maiani and Testa, and then review methodology to circumvent said limitations. The first main example of the latter is the formalism of Luscher to analyze elastic scattering and a second is the method of Lellouch & Luscher to analyze weak decays. I will then proceed to discus recent theoretical generalizations of these frameworks that allow for the determination of scattering amplitudes, resonances, transition and elastic form factors. Finally, I will outline outstanding problems, including those that are now beginning to be addressed.

Plenary / 94

QPACE 2 and Domain Decomposition on the KNC

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I will give an overview of QPACE 2, which is a custom-designed machine based on Intel Xeon Phi processors, developed by Regensburg University in collaboration with Eurotech (Italy/Japan). I will also discuss our high-performance implementation of a domain-decomposition-based solver on the Xeon Phi and present benchmarks of its strong-scaling behavior.

Plenary / 95

Long Distance Effects from the Lattice

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Theoretical Developments / 96

Grassmann Tensor Renormalization Group Study of Lattice QED with Theta Term in Two Dimensions

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The tensor renormalization group is one of the successful methods to tackle systems whose action is complex, though the practical calculations in higher dimensions is beyond the reach of current computer facilities. The Grassmann tensor renormalization group is a generalization to systems including fermions. As a pilot study toward lattice QCD, we apply it to two-dimensional lattice QED and investigate its phase structure with the theta term.

Plenary / 97

Conference Closing

Physics beyond the standard model / 98

Phase structure and Higgs boson mass in a Higgs-Yukawa model with a dimension-6 operator

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We investigate the impact of a $\lambda_6 \pi^6$ term included in a
chiral invariant lattice Higgs-Yukawa model. Such a term could emerge from BSM physics at some larger energy scale.
We map out the phase structure of the Higgs-Yukawa model with positive
λ_6 and negative quartic self coupling. To this
end, we evaluate the constraint effective potential in lattice perturbation theory and determine the magnetization of the model
via numerical simulations which allow us to reach also non-perturbative values of the couplings. As a result, we find a complex phase structure with first and second order phase transitions identified through the magnetization.
Further we analyze the effect of such a ϕ^6 term on the Higgs boson
mass to see, whether the standard model lower mass bound
can be altered.

Application beyond QCD / 99

Hybrid-Monte-Carlo simulation of the tight-binding model of graphene with partially screened Coulomb interactions

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We report on the status of our ongoing Hybrid-Monte-Carlo simulations of the tight-binding model for the electronic properties of graphene, using a realistic potential for the two-body interactions.
Our short-range interactions thereby include the partial screening due to electrons in higher energy states from ab initio calculations based on the constrained random phase approximation [T.O.Wehling et al., Phys.Rev.Lett. 106, 236805 (2011)].
We also include a phenomenological model which describes the transition to the unscreened bare Coulomb interactions of graphene at half filling in the long-wavelength limit.
We present up-to-date results on the transition from the semimetal
to an antiferromagnetic insulating phase and outline a number of additional problems which will be addressed using our code.

Physics beyond the standard model / 100

Improved gradient flow for step scaling function and scale setting

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The gradient flow renormalized coupling offers a relatively inexpensive way to calculate the step scaling function or the lattice scale, but both applications can be hindered by large lattice artifacts. Recently we introduced an empirical non-perturbative improvement that can remove O(a^2) lattice artifacts. The method is easy to implement and can be applied to any lattice gauge theory of interest both in step scaling studies and for scale setting. In this talk I will briefly review this improvement method and discuss its application to 4, 8 and 12 flavor systems in step scaling function studies and for scale setting in 2+1+1 flavor QCD.

Poster session - Board 8 / 101

The mass of the adjoint pion in N=1 supersymmetric Yang-Mills theory

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In Monte Carlo simulations of $\mathcal{N}=1$ supersymmetric Yang-Mills theory the mass of the unphysical adjoint pion, which is easily obtained numerically, is being used for the tuning to the limit of vanishing gluino mass. We show how to define the adjoint pion in the framework of partially quenched chiral perturbation theory and we derive a relation between its mass and the mass of the gluino analogous to the Gell-Mann-Oakes-Renner relation of QCD.

Theoretical Developments / 102

Lattice Hamiltonian approach to the Schwinger model

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We employ exact diagonalization with strong coupling expansion to the massless and massive Schwinger model. For the massless case, this allows us for a high accuracy continuum limit estimation of the ground state energy and scalar and vector mass gaps with precisions of the order of one part per billion or better.
Furthermore, we investigate the chiral condensate and compare our calculations to previous results available in the literature. Oscillations of the chiral condensate which are present while increasing the expansion order are also studied and are shown to be directly linked to the presence of flux loops in the system.

Hadron Structure / 103

A new strategy for evaluating the LO HVP contribution to (g-2)_mu on the lattice

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We propose a hybrid strategy for the lattice evaluation of the leading order hadronic vacuum polarization contribution to the anomalous magnetic moment of the muon. The strategy combines direct numerical integration of lattice data for Q^2 greater than Q^2_min with the use of fit forms to handle the lattice data in the low-Q^2 region Q^2 less than Q^2_min. Using a physical model for the I=1 subtracted vector polarization, constructed from experimental data, we study the systematics of this strategy, determining how low a choice of Q^2_min is possible for current lattice simulations, and identifying three types of fit forms whose use in the low-Q^2 region will lead to results with systematic uncertainties well below the 1% level.

Theoretical Developments / 104

Triviality of ϕ^4_4 in the broken phase revisited

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We define a finite size renormalization scheme for ϕ^4 theory which in the thermodynamic limit reduces to the standard scheme used in the broken phase. We use it to re-investigate the question of triviality for the four dimensional infinite bare coupling (Ising) limit. The relevant observables all rely on two-point functions and are very suitable for a precise estimation with the worm algorithm.

Physics beyond the standard model / 105

Phase structure of the N = 1 supersymmetric Yang-Mills theory at finite temperature

Mr. PIEMONTE, Stefano [1]; Prof. MÜNSTER, Gernot [1]; Dr. BERGNER, Georg [2]; Dr. GIUDICE, Pietro [1]; Mr. SANDBRINK, Dirk [1]

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The behaviour of supersymmetric theories at finite temperatures differs from that of other theories in certain aspects. Due to the different thermal statistics of bosons and fermions, supersymmetry is explicitly broken for any non-zero value of the temperature. We study the N=1 supersymmetric Yang-Mills theory on the lattice at finite temperatures. This model is the simplest supersymmetric extension of the pure gauge sector of QCD, describing the interactions between gluons and their fermionic superpartners, the gluinos. At zero temperature the theory confines like QCD, and chiral symmetry is spontaneously broken. At high temperatures, deconfinement and chiral symmetry restoration are expected to take place, but it is not known whether these two phase transitions coincide or not. First results on this topic, obtained in numerical simulations, will be presented and discussed.

Theoretical Developments / 107

How to reduce O(a^2) effects in gradient flow observables?

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The gradient flow has become a very useful tool both for scale setting and for defining suitable finite volume schemes for the gauge coupling. However, surprisingly large cutoff effects have been observed in some cases. We here investigate these effects at leading order in perturbation theory and reproduce qualitative features that have previously been observed in the context of scale setting. We demonstrate that the leading O(a^2) effects can be completely eliminated through a combined improvement of the observables, the action and the gradient flow.
We then focus on finite volume couplings with SF boundary conditions
and analyze the size of remaining cutoff effects, both from the bulk and the boundaries. This leads us to the definition of our preferred set-up and preliminary simulation results in the pure SU(3) gauge theory corroborate our findings.

Hadron Structure / 108

Nucleon transverse momentum-dependent parton distributions from domain wall fermion calculations at 297 MeV pion mass

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Lattice QCD calculations of transverse momentum-dependent parton distributions (TMDs) in a nucleon are performed based on a definition of TMDs via hadronic matrix elements of quark bilocal operators containing staple-shaped gauge connections. A parametrization of the matrix elements in terms of invariant amplitudes serves to cast them in the Lorentz frame preferred for the lattice calculation. Using a RBC/UKQCD domain wall fermion ensemble corresponding to a pion mass of 297 MeV, on a lattice with spacing 0.084 fm, selected TMD observables are accessed and compared to previous explorations at heavier pion masses on coarser lattices.

Physics beyond the standard model / 109

Lattice Formulations of Supersymmetric Gauge Theories with Matter Fields

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Certain classes of supersymmetric gauge theories, including the well known N=4 super Yang-Mills (SYM) theory, that takes part in the AdS/CFT correspondence, can be formulated on a Euclidean spacetime lattice using the techniques of exact lattice supersymmetry. Great ideas such as topological twisting, Dirac-Kahler fermions, geometric discretization all come together to create gauge theories that are exact-supersymmetric, gauge-invariant, local and doubler-free on the lattice. In this talk we present the lattice formulations of specific classes SYM theories with matter fields in various representations of the gauge group. We hope that such constructions may further motivate the lattice study of technicolor theories, orbifolding and orientifolding in string theories and Corrigan-Ramond limit.

Hadron spectroscopy and interaction / 110

Spectroscopy of charmed baryons from lattice QCD

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We present the ground and excited state spectra of triply, doubly and singly-charmed baryons by using dynamical lattice QCD. A large set of baryonic operators that respect the symmetries of the lattice and are obtained after subduction from their continuum analogues are utilized. Using novel computational techniques correlation functions of these operators are generated and the variational method is exploited to extract excited states. The lattice spectra that we obtain have baryonic states with well-defined total spins up to $\frac{7}{2}$ and the low lying states remarkably resemble the expectations of quantum numbers from SU(6)$\times$ O(3) symmetry. Various energy splittings between the extracted states, including splittings due to hyperfine as well as spin-orbit coupling, are considered and those are also compared against similar energy splittings at other quark masses.

Hadron Structure / 111

Background field method and nonrelativistic QED matching

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We discuss the resolution of inconsistencies between the background field method in lattice QCD and the effective field theory matching conditions. Lack of on-shell conditions in lattice QCD with time-dependent background fields requires that operators related by equations of motion in the effective field theory should be retained in the action to describe the Green's function correctly. As a concrete example, we perform a robust non-relativistic expansion of the relativistic QED action for scalar and spin-half hadrons under uniform electromagnetic fields, and obtain the nonrelativistic QED matching conditions including the equation-of-motion operators. For a scalar hadron, this result is also supported by the matching at the level of the Green's function. The method is extended to treat the proton in uniform electric and magnetic fields, where Landau levels are addressed in the latter case to allow determination of the magnetic polarizability.

Vacuum Structure and Confinement / 112

The static three-quark potential from the Polyakov loop correlation function

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We study the static three-quark potential in SU(3) lattice gauge theory at zero temperature with the Polyakov loop correlation function (PLCF) consisting of three Polyakov loops.
Compared to the use of the three-quark Wilson loop, the PLCF allows us to investigate
the ground state potential of various three-quark configurations in detail with less systematic effects.
We overcome the problem of the statistical errors by employing the multi-level algorithm
and obtain remarkably clean signals.
We present these results and discuss the possible shape of the confining string for the three-quark system.

Poster session - Board 23 / 113

Comparative study of topological charge

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Comparative study of topological charge is performed.
Topological charges are measured by a cloverleaf operator
on smoothed gauge configurations.
Various types of smoothing techniques are employed.
We investigate
to what extent each smoothing makes the topological charge an integer.
Consistency of the topological charge in the fermionic definition
is also examined.

Hadron spectroscopy and interaction / 114

Evidence for the charged charmonium-like state Zc+ from lattice QCD

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We perform a lattice QCD simulation of the charmonium-like channel, where experiments recently found several manifestly exotic states named Zc+ with flavor content bar c c bar d u. In addition to identifying all the scattering states we also observe an additional level in the simulation, which we attribute to Zc+.

Theoretical Developments / 115

Non-perturbative renormalization of the energy-momentum tensor in SU(3) Yang-Mills theory

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We report on an ongoing project of determining non-perturbatively the finite renormalization constants of the energy-momentum tensor in the SU(3) Yang-Mills theory. We compute them by imposing on the lattice suitable Ward Identites at finite temperature and volume in presence of shifted boundary conditions. We present accurate preliminary numerical data for values of the bare coupling g_0^2 ranging for 0 to 1.

Hadron spectroscopy and interaction / 116

Nucleon spectroscopy using multi-particle operators

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The role of 5-quark operators in extracting the nucleon excited state spectrum via correlation matrix techniques is explored. In particular, the coupling of meson-baryon operators to nucleon resonance states and scattering states is studied. Results are presented for 2+1 flavour dynamical ensembles in both the positive and negative parity channels.

Application beyond QCD / 117

Spontaneous chiral symmetry breaking and chiral magnetic effect in Weyl semimetals

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We study interacting Dirac fermions with chiral imbalance (modelled by a chiral chemical potential) in the mean-field approximation and find that the chiral imbalance is strongly enhanced due to spontaneous chiral symmetry breaking. We then consider the Chiral Magnetic Effect (CME) in the linear response approximation and find that in a phase with broken chiral symmetry the CME current is saturated by vector mesons with different polarizations, which are mixed in chirally imbalanced matter. It turns out that strong screening of CME current in this phase is exactly compensated by enhancement of chiral imbalance, so that the chiral magnetic conductivity remains finite in the strong-coupling limit. We illustrate these conclusions for a Weyl semimetal which is modelled by a single flavour of Wilson-Dirac fermions with chiral chemical potential. We also argue that this model is free of the sign problem by virtue of time-reversal symmetry and can be efficiently simulated using the Rational Hybrid Monte-Carlo algorithm.

Poster session - Board 26 / 118

Extraction of the isovector magnetic form factor of the nucleon at zero momentum

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The extraction of the magnetic form factor of the nucleon at zero momentum transfer is usually performed by adopting a parametrization for its momentum dependence and fitting the results obtained at finite momenta. We present methods that rely on taking the derivative of relevant correlators to extract directly the magnetic form factor at zero momentum without the need to assume a functional form for its momentum dependence. These methods are explored on one ensemble using N_f=2+1+1 Wilson twisted mass fermions.

Chiral Symmetry / 119

Mesons upon low-lying Dirac mode exclusion

Mr. DENISSENYA, Mikhail [1]; Prof. GLOZMAN, Leonid [1]; Prof. LANG, Christian [1]

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We study the iso-scalar and iso-vector mesons under the exclusion of the low-lying Dirac modes from valence quarks with the overlap operator within the two flavour lattice QCD. We study mesonic correlators and extract states at each level of such low-mode truncation. Our observations support a simultaneous restoration of both SU(2)_L \times SU(2)_R and U(1)_A symmetries. We finally observe a degeneracy of all isovector and isoscalar J=1 mesons that serves as an indication of some higher symmetry in the chirally restored regime.

Theoretical Developments / 120

Induced QCD with Nc auxiliary bosonic fields

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We investigate an alternative lattice discretization of continuum SU(Nc) Yang-Mills theory in which the self-interactions of the gauge field are induced by a path integral over Nc auxiliary bosonic fields which are coupled linearly to the gauge field. In two dimensions there exists an analytic proof that the new discretization reproduces Yang-Mills theory in its non-perturbative continuum limit. We provide numerical evidence that this is also the case in three and four dimensions and that, after a suitable matching between the free parameters, the results of the induced theory agree with results from the ordinary plaquette action up to lattice artifacts. The new discretization is ideally suited to change the order of integration in the QCD path integral to arrive at formulations in which the gauge fields have been integrated out. The resulting theories might be amenable to methods previously used in the infinite-coupling limit, and we briefly discuss a possible dual representation of lattice QCD.

Application beyond QCD / 121

Hybrid Monte Carlo simulations of Graphene in presence of vacancies

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Tight-binding model of Graphene with vacancies in crystal structure was studied within the framework of Hybrid Monte Carlo simulations.
Antiferromagnetic ordering is observed in the vicinity of the vacant sites. Mass gap is extracted from the calculations of the two-point Euclidean Green function. It is demonstrated that even a relatively small concentration of vacancies can lead to opening a mass gap in monolayer Graphene.

Weak Decays and Matrix Elements / 122

The scalar B meson in the static limit of HQET

Mr. GÉRARDIN, Antoine [1]; Dr. BLOSSIER, Benoit [1]

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I will present results on the scalar B meson (B_0^*) sector using $N_f=2$ $\mathcal{O}(a)$-improved Wilson-Clover fermions and the Heavy Quark Effective Field theory at the static limit to describe the b-quark. Since the scalar B meson lies near the B π threshold for our simulations set-up, we have implemented meson-meson as well as quark-antiquarks interpolating fields to disentangle the scalar B meson from the two particles states. Using the Generalized Eigenvalue Problem on the full basis, we are able to separate the two levels. Then, we compute the scalar B meson decay constant and the couplings h which parametrizes the Heavy Meson Chiral Perturbation Theory Lagrangian, more precisely the transitions between the $1/2^+$ and $1/2^-$ heavy-light mesons doublets. The couplings h may play a role in the chiral extrapolations when taking the nearest orbital excitations into account in chiral loops.

Poster session - Board 13 / 123

Study of the Theta Angle in Scalar QED_2 in a Dual Representation

Mr. KLOIBER, Thomas [1]; Prof. GATTRINGER, Christof [1]

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We study the effect of the theta angle in two dimensional scalar QED. Since the theta term is purely imaginary, it introduces a complex action problem which prevents conventional numerical simulations at non-zero values of theta. This problem is solved by mapping the model to a dual representation, which is real and non-negative, hence suitable for Monte Carlo simulations. We present technical aspects of the reformulation as well as physical results concerning, e.g., the topological charge.

Poster session - Board 10 / 124

Testing the density of states method for the effective center model of QCD

Mr. TOEREK, Pascal [1]; Dr. DELGADO MERCADO, Ydalia [1]; Prof. GATTRINGER, Christof [1]

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We use the density of states method to compute the observables of the effective center model of QCD at finite density (where the system suffers from a complex phase problem). The density of states method is a reweighting method based on an improved evaluation of histograms for the distribution of states. We test this approach against the results from the dual simulations of the model, where the sign problem is absent.

Hadron spectroscopy and interaction / 125

Lattice study of pion-pion scattering using Nf=2+1 Wilson improved quarks with masses down to their physical values.

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for the BMW Collaboration.

We use 2HEX smeared gauge configurations generated with the Nf=2+1 clover improved Wilson action to investigate pion-pion scattering in the rho channel. The range of lattice spacings (0.054 fm to 0.12 fm) and space-like extents (32 and 48) allows us to extract the scattering parameters through the volume dependence of the effective mass according to Luscher's formalism. In particular, we consider bases of up to 5 operators to extract these levels. Our pion masses, down to 134 MeV, allow us to begin studying the light-quark-mass dependence of the resonance parameters.

Physics beyond the standard model / 126

Composite (Goldstone) Higgs Dynamics on the Lattice: Spectrum of SU(2) Gauge Theory with two Fundamental Fermions

Prof. PICA, Claudio [1]; Prof. SANNINO, Francesco [1]; Dr. HIETANEN, Ari [1]; Dr. ARTHUR, Rudy [1]; Dr. DRACH, Vincent [1]; Prof. LEWIS, Randy [2]

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We study the meson spectrum of SU(2) gauge theory with two Wilson fermions in the fundamental representation. The theory unifies both Technicolor and composite pseudo Goldstone Boson (pGB) Higgs models of electroweak symmetry breaking. We have calculated the masses of the lightest spin one vector and axial vector mesons. In addition, we have also obtained preliminary results for the mass of the lightest scalar (singlet) meson state. The simulations have been done with multiple masses and two different lattice spacings for chiral and continuum extrapolations. The spin one meson masses set lower limits for accelerator experiments, whereas the scalar meson will mix with a pGB of the theory and produce two scalar states. The lighter of the states is the 125 GeV Higgs boson, and the heavier would be a new yet unobserved scalar state.

Vacuum Structure and Confinement / 127

The dynamical QCD string

Prof. GLOZMAN, Leonid Glozman [1]; Mr. DENISSENYA, Mikhail [1]; Prof. LANG, Christian [1]

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Using the overlap Dirac operator we remove its
lowest-lying eigenmodes from the valence quark
propagators and study evolution of the J=1 meson
masses. At the truncation energy about 50 MeV we
observe a degeneracy of all possible U(2)_L * U(2)_R
multiplets, i.e. the observed quantum levels have
a symmetry larger than U(2)_L * U(2)_R and their
energy does not depend on the spin orientation of quarks
and their parities. We interpret these energy levels
as the quantum levels of a dynamical QCD string that
connects the ultrarelativistic quark and antiquark.

Hadron Structure / 128

Glue Helicity ΔG In the Nucleon

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We present a lattice QCD calculation of the glue helicity ΔG in the nucleon for the first time.
It is recently shown that the first moment of the glue helicity distribution can be obtained through the product of the the electric field $\vec{E}$ and the gauge field in the Coulomb gauge $\vec{A}_C$, i.e. $\vec{E} \times \vec{A}_C$ in the infinite momentum frame. We used the gauge field tensor from the overlap Dirac operator to check the frame dependence with several momenta. The calculation is carried out with valence overlap fermion on 2+1 flavor DWF gauge configurations on the $24^3 \times 64$ lattice with the light sea quark mass corresponds to a pion mass of 330 MeV.

Hadron spectroscopy and interaction / 129

Finite volume effects and the electromagnetic contributions to kaon and pion masses

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We report on the MILC Collaboration calculation of electromagnetic effects on light pseudoscalar mesons. The simulations employ asqtad staggered dynamical quarks in QCD plus quenched photons, with lattice spacings varying from 0.12 to 0.06 fm. Finite volume corrections for the MILC realization of lattice electrodynamics have been calculated in chiral perturbation theory theory and applied to the lattice data. These corrections differ from those calculated by Hayakawa and Uno because our treatment of zero modes differs from theirs. Updated results for the corrections to "Dashen's theorem" are presented.

Hadron spectroscopy and interaction / 130

K-pi scattering lengths at physical kinematics

Mr. JANOWSKI, Tadeusz [1]

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I will present preliminary results on K-pi scattering lengths obtained by the RBC-UKQCD collaboration. The results are obtained using one of our domain wall fermion ensembles with physical quark masses.
I will argue that the large "around-the-world" effects which are present with such light quark masses can be controlled.

Vacuum Structure and Confinement / 131

Topological insulators and the QCD vacuum.

Prof. H. B., Thacker [1]

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There is considerable evidence, based on large N_c chiral dynamics, holographic QCD, and Monte Carlo studies, that the topological structure of the QCD vacuum consists of discrete quasivacua separated by domain walls across which the local value of the topological θ parameter jumps by $\pm2\pi$.
Topological insulators are condensed matter systems which are bulk insulators with a mass gap but which can transport quantized units of charge via topologically protected boundary states. This is analogous to the QCD vacuum, where the pure glue theory has a bulk mass gap but, when light quarks are included, has Goldstone bosons associated with topological modes of the Dirac operator. As in topological insulators, Goldstone modes in QCD are boundary states on codimension one membranes or domain walls. Following this analogy, the U(1) chiral field in QCD is given by the closed loop integral of a Berry connection around the Brillouin zone in lattice momentum space. This berry phase describes the local polarization of the topological charge membranes.

Hadron spectroscopy and interaction / 132

Relativistic three-particle quantization condition: an update

Prof. SHARPE, Stephen [1]; Mr. HANSEN, Maxwell [1]

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Last year, we presented a generalization of Luescher's two-particle quantization condition to three identical, degenerate particles.
While completing this work, we discovered a technical problem with our derivation which invalidated the result, in the sense that not all finite-volume corrections that fall as powers of the box size were controlled. We have found
a fix to this problem, which maintains the form of our original result, but involves a new infinite-volume quantity that is
not directly related to the three-particle scattering amplitude.
We will sketch the problem and its resolution,
and discuss the practical utility of our result.

Theoretical Developments / 133

A construction of the Schrodinger Functional for Möbius Domain Wall Fermions

Ms. MURAKAMI, Yuko [1]; Prof. ISHIKAWA, Ken-Ichi [1]

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We investigate the universality of Möbius Domain Wall Fermions (MDWF) in the Schrödinger Functional (SF) scheme at tree level. We introduce the SF boundary condition to the MDWFs by adding a temporal boundary operator. When the fifth dimensional parameters of the MDWF are a constant, this construction seems to be natural according to the Luescher's universality prescription for the overlap fermion and Takeda's construction for the standard domain wall fermion (DWF). We observe that the four dimensional effective operator derived from this DWF approaches to the continuum operator with the SF boundary condition at tree level. In order to construct the SF boundary condition for the Optimal DWFs, the fifth dimensional parameters depend on the fifth lattice index, we must impose the fifth dimensional parity symmetry on the parameters so as to maintain both the discrete symmetries and the chiral symmetry breaking property of the SF boundary term. This additional symmetry makes the MDWF with the SF boundary condition impossible to introduce Zolotarev optimal coefficients. We will discuss how to realize the optimal type of the MDWF with the SF boundary condition.

Chiral Symmetry / 134

Phase diagram of non-degenerate twisted mass fermions

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In this talk, I will summarize recent work with Prof. Stephen Sharpe in mapping out the phase diagram and pion spectrum for chiral perturbation theory with twisted-mass fermions in the presence of non-degeneracy between the up and down quark and discretization errors. I will show how the CP-violating phase of the continuum theory, which occurs for sufficiently large non-degeneracy, is continuously connected to the Aoki-phase found in the lattice theory with degenerate quarks. Both for the Aoki-phase and first-order scenarios, this results in a critical surface along which at least one of the pions is massless. In the pion spectrum, I will focus mainly on the maximal twist case, where there is competition between the effects of non-degeneracy and twist-dependent discretization errors, resulting in a complete breakdown of isospin symmetry with all three pions having different masses. This breakdown of isospin symmetry should be a useful indicator of the size of discretization errors as simulations with twisted-mass fermions move to non-degenerate masses. Lastly, I will show numerical results for the effects of higher order terms on the phase diagram and the pion spectrum.

Physics beyond the standard model / 135

The gradient flow running coupling in SU2 with 8 flavors

Dr. RANTAHARJU, Jarno [1]; Prof. RUMMUKAINEN, Kari [2]; Dr. KARAVIRTA, Tuomas [3]; Dr. TUOMINEN, Kimmo [2]; Mr. RANTALAIHO, Teemu [2]; Mr. LEINO, Viljami [2]

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We present preliminary results of the gradient flow running coupling with Dirichlet boundary condition in the SU(2) gauge theory with 8 fermion flavors. Improvements to the gradient flow measurement allow us to obtain a robust continuum limit. The results are consistent with perturbative running in the weak coupling region and show slow running at strong coupling.

Hadron spectroscopy and interaction / 136

Omega-Omega interaction from 2+1 flavor QCD

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We report our results of central potential between two Omega baryons
from 2+1 flavor full Lattice QCD simulation.In the past studies, there is
a possibility that some decuplet baryons have a bound state.
However, almost all decuplet baryons are unstable due to decays via the strong interaction.
An exception is the Omega decuplte baryon, which is stable against the strong decays,
so its interaction is suitable to be investigated.
It is, however, still difficult to investigate the Omega-Omega interaction
experimentally due to its short-life time via weak decays.Therefore, the lattice QCD
study for the Omega-Omega interaction is necessary and important.

We present results obtained by the extension of the HAL QCD method to the system of two decuplet baryons.
Our numerical results are obtained from 2+1 flavor full QCD gauge configurations at
$L \sim 2.9 $fm $m_\pi \sim 701 $MeV $ and m_\Omega\sim 1966 , generated by the PACS-CS Collaboration.
We find that the Omega-Omega interaction is strong attractive, but it's not strong enough to make a bound state at out simulation set up.

Physics beyond the standard model / 137

SU(3) gauge theory with 12 flavours in a twisted box

Prof. LIN, C.-J. David [1]; Dr. OGAWA, Kenji [2]; Dr. OHKI, Hiroshi [3]; Dr. RAMOS, Alberto [4]; Dr. SHINTANI, Eigo [5]

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We present our study of the running coupling constant in SU(3) gauge theory with 12 flavours of fermions. In this work we use the method of the step scaling, implemented on lattices with twisted boundary condition. The lattice volumes in this work are 6, 8, 10, 12, 16, 20, and 24. This choice of volumes enables us to investigate the systematic effects in the continuum extrapolation. We discuss in detail the approach of using the Wilson Flow for extracting the coupling constant via the computation of the energy density. In particular, we present results obtained with two different lattice discretisations (clover and the plaquette) of the energy density. Our results shed light on the recent controversy over the infrared behaviour of this gauge theory. Finally, we also briefly comment on the coupling constant computed using the Twisted Polyakov Loop scheme.

Hadron Structure / 138

Results on the disconnected contributions for hadron structure

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We present results for $N_f=2+1+1$ twisted mass fermions on the disconnected contributions to the three point functions entering in studies of hadron structure. Emphasis is given to the nucleon sigma-terms, isoscalar axial charge and first moments of parton distributions for a range of pions masses. The computations are performed using QUDA code implemented on GPUs.

Vacuum Structure and Confinement / 139

Centre Vortex Effects on the Overlap Quark Propagator

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The fundamental aspects of the QCD vacuum that are responsible for the dynamical generation of mass through chiral symmetry breaking is an ongoing source of debate. We investigate the role of centre vortices in dynamical mass generation using overlap fermions. The exact chiral symmetry that the overlap fermion action possesses yields a distinctive response to the underlying topology of the gauge field,
leading to novel results. We study the quark propagator and associated mass function on gauge- field backgrounds featuring the removal of centre vortices as well as on vortex-only backgrounds. The effect of cooling vortex-only backgrounds on the overlap quark propagator is also presented.

Poster session - Board 2 / 140

Overlap Quark Propagator in Coulomb Gauge QCD

Dr. PAK, Markus [1]; Dr. DELGADO, Ydalia [1]; Dr. SCHRÖCK, Mario [2]

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The chirally symmetric Overlap quark propagator is explored for the first time in Coulomb gauge. This gauge is well suited for studying the relation between confinement and chiral symmetry breaking. The dressing functions of the quark propagator and the dynamical mass function are evaluated. Chiral symmetry is then artificially restored by removing the low eigenmodes from the Dirac operator. Its effect on the dressing functions is discussed. Via a quark dispersion relation it is shown that confinement is still intact after artificially restoring chiral symmetry.

Hadron Structure / 141

Computing the nucleon sigma terms at the physical point

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The nucleon sigma terms are quantities that play a crucial role in phenomenology: among others, they connect the pion-nucleon and the kaon-nucleon amplitudes to the hadron spectrum and they are also relevant for the direct detection of Dark Matter (DM).
We present preliminary results for these sigma terms obtained from N_f=2+1 lattice simulations that are performed at five lattice spacings and for pion masses all the way down to its physical value.

(Christian Torrero for the Budapest-Marseille-Wuppertal (BMW) collaboration)

Physics beyond the standard model / 142

Phase Structure Study of SU(2) Lattice Gauge Theory with 8 flavours

Ms. HUANG, Cynthia Yu-Han [1]; Prof. LIN, C.-J. David [1]; Mr. OGAWA, Kenji [2]; Mr. OHKI, Hiroshi [3]; Mr. RINALDI, Enrico [4]

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We present the phase structure for SU(2) lattice gauge theory with 8 flavours of staggered fermions in the fundamental representation. One bulk phase transition is observed through the measurement of the plaquette, smeared Polyakov loops, as well as the Dirac operator eigenvalue spectrum. To further identify the order of the bulk phase transition pertaining to confinement and deconfinement, we resort to cold-start and hot-start simulations and the study of the constraint effective potential relating to distributions for smeared Polyakov loops.

Poster session - Board 3 / 143

Perturbative and non-perturbative renormalization results of the Chromomagnetic Operator on the Lattice

Dr. CONSTANTINOU, Martha [1]; Mr. COSTA, Marios [1]; Prof. FREZZOTTI, Roberto [2]; Prof. LUBICZ, Vittorio [3]; Prof. MARTINELLI, Guido [4]; Dr. MELONI, Davide [3]; Prof. PANAGOPOULOS, Haralambos [1]; Prof. SIMULA, Silvano [3]

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The chromomagnetic operator mixes with a large number of operators under renormalization. We identify which operators can mix with the chromomagnetic operator, at the quantum level. Even in dimensional regularization (DR), which has the simplest mixing pattern, the chromomagnetic operator mixes with a total of 9 other operators,forming a basis of dimension-five (d=5), Lorentz scalar operators with the same flavor content as the chromomagnetic operator. Among them, there are also gauge noninvariant operators; these are BRST invariant and vanish by the equations of motion, as required by renormalization theory. On the other hand using a lattice regularization further operators with equal or lower dimensionality will mix; choosing the lattice action in a manner as to preserve certain discrete symmetries, a minimul set of 3 additional operators (all with d<5) will appear. In order to compute all relevant mixing coefficients, we calculate the quark-antiquark (2-pt) and the quark-antiquark-gluon (3-pt) Green's functions of the chromomagnetic operator at nonzero quark masses. These calculations were performed in the continuum (dimensional regularization) and on the lattice using the maximally twisted mass fermion action and the Symanzik improved gluon action. In parallel, non-perturbative measurements of the K-π matrix element are being performed in simulations with 4 dynamical (N_f = 2+1+1) twisted mass fermions and the Iwasaki improved gluon action.

Application beyond QCD / 144

Monte-Carlo study of the phase transition in the AA-stacked bilayer graphene

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Tight-binding model of the AA-stacked bilayer graphene with screened
electron-electron interactions has been studied using the Hybrid Monte
Carlo simulations on the original double-layer hexagonal lattice.
Instantaneous screened Coulomb potential is taken into account using
Hubbard-Stratonovich transformation. G-type antiferromagnetic ordering has been studied and the phase transition with spontaneous generation of the mass gap has been observed. Dependence of the energy gap on the on-site electron-electron interaction is examined. It is found, that the energy gap vanishes at some finite value of the on-site interaction potential, which differs from the dependence, predicted by the mean-field approximation.

Application beyond QCD / 146

Asymptotic safety on the lattice: the nonlinear O(N) Sigma model

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We study the non-perturbative renormalization group flow of the nonlinear O(N) sigma model in two and three space-time dimensions using a scheme that combines an effective local Hybrid Monte Carlo update routine, blockspin transformations and a Monte Carlo demon method. In two dimensions our results verify perturbative renormalizability. In three dimensions, we determine the flow diagram of the theory for various N and different truncations and find a non-trivial fixed point, which indicates non-perturbative renormalizability. It is related to the well-studied phase transition of the O(N) universality class and characterizes the continuum physics of the model. We compare the obtained renormalization group flows with recent investigations by means of the Functional Renormalization Group.

Plenary / 148

Measurement of thermodynamics using Gradient Flow

Prof. ASAKAWA, Masayuki [1]; Prof. SUZUKI, Hiroshi [2]; Prof. KITAZAWA, Masakiyo [1]; Dr. ITOU, Etsuko [3]; Dr. HATSUDA, Tetsuo [4]; Dr. IRITANI, Takumi [5]

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We propose a novel method to define and calculate the energy-momentum tensor (EMT) in lattice gauge theory on the basis of the Yang-Mills gradient flow.
Using this method, we measure the thermodynamics of SU(3) gauge theoy on fine
lattices with lattice size up to 64^3x18.
The numerical results with small lattice spacing confirm our previous findings;
the expectation values of the EMT have reasonable dependences on the flow time
near the continuum limit, and thus our method can successfully be applied to the
analysis of the EMT on the lattice.

Algorithms and Machines / 149

A Method to Calculate Conserved Currents and Fermionic Force for the Lanczos Approximation to the Overlap Dirac Operator

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The overlap Dirac operator at finite chemical potential can be efficiently computed with the two-sided Lanczos algorithm. Compared with other methods the Lanczos algorithm has the advantage that it takes into account information about the source vector when constructing an approximation to the overlap operator.
In order to study transport coefficients in terms of correlators of conserved currents or to calculate the fermionic force in Hybrid Monte-Carlo simulations with the Lanczos approximation to overlap, one needs to calculate the derivative of this approximate overlap operator over the gauge field. We found that a straightforward algorithmic differentiation approach leads to huge numerical errors and is not feasible even for small lattice sizes.
In this talk we argue that it is possible to simultaneously compute the action of the overlap operator and its derivative on a source vector. Using a matrix function identity, found by R. Mathias, we show that the calculation can be done without knowledge of the derivative of the Lanczos algorithm. To this end one has to apply the Lanczos algorithm to a block Toeplitz matrix of some special form, which acts on the linear space with two times larger dimension than the dimension of the original overlap operator. We present preliminary results and show that our method is numerically stable.

Hadron spectroscopy and interaction / 150

Electromagnetic mass splittings from dynamical lattice QCD+QED

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First results on electromagnetic mass splittings of octet mesons and baryons from a fully dynamical simulation of QCD+QED are presented.

Algorithms and Machines / 151

pyQCD: A Native Lattice Simulation Package for Python

Mr. SPRAGGS, Matthew [1]

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I demonstrate pyQCD, a native Python library providing an extensible API for single-node lattice measurements and simulations. Boost.Python is used to wrap the underlying C++ code and expose an interface to Python for the generation of propagators and configurations, both of which are returned as numpy ndarray types. The library can take advantage of GPU technology by using CUDA where possible to accelerate Dirac operator inversions. The package provides a set of tools for rapid prototyping and testing of algorithms or lattice measurements prior to their implementation in production code.

Standard model parameters and renormalization / 152

A Feynman-Hellmann approach to nonperturbative renormalization of lattice operators

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Renormalization factors are needed to related lattice quantities to their corresponding continuum counterparts. In order to renormalize singlet observables one has to include connected and disconnected diagrams. Especially, the disconnected contributions are very difficult to calculate using the standard three-point function technique. The Feynman-Hellmann method provides the possibility to calculate the renormalization factors from two-point functions from which much better signals can be extracted. However, one has to simulate with additional modified actions.
In this talk we present first results for the Nf=2+1 SLiNC action. We compute the renormalization factors of selected local operators for the non-singlet and singlet cases.

Application beyond QCD / 153

Beta function of three-dimensional QED

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We have carried out a Schrodinger-functional calculation for the Abelian gauge theory with Nf=2 four-component fermions in three dimensions. We find no fixed point in the beta function, meaning that the theory is confining rather than conformal.

Standard model parameters and renormalization / 154

Calculating the glue helicity on the lattice with comments about renormalization

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We discuss recent preliminary results for a lattice calculation of the glue helicity Δ_G in the Coulomb gauge. We have used the gauge field tensor defined from the overlap Dirac operator. The calculation is carried out with valence overlap quarks on 2+1 DWF gauge
configurations on the $24^3 \times 64$ lattice which corresponds to a pion mass of 330 MeV. Finally, we discuss the perturbative renormalization matching of this operator to the continuum $\overline{MS}$ scheme at one-loop order in the Coulomb gauge.

Poster session - Board 27 / 155

Quark mass dependence of finite temperature phase transitions in QCD with many flavors of Wilson fermions

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We investigate the phase transitions of (2+Nf)-flavor QCD, where two light flavors and Nf massive flavors exist, to discuss the electroweak baryogenesis in realistic technicolor scenario. Because an appearance of a first order phase transition at finite temperature is a necessary condition for the baryogenesis, it is important to study the nature of phase transition in the case of massless 2 flavors. Performing simulations of 2-flavor QCD with Wilson fermions and using the reweighting method, we calculate probability distribution functions of the many-flavor QCD. Through the shape of the distribution function, we determine the boundary of the first order region in the parameter space of the light quark mass and heavy quark mass. It is found that the light quark mass dependence of the critical mass of heavy quarks is very small in the region we investigated. From the light quark mass dependence, it is even possible to extract the nature of the transition of massless 2-flavor QCD. Our current result of small dependence suggests that the critical mass of heavy quark remains finite in the chiral limit of 2-flavors and there exists a second order transition region on the line of the 2-flavor massless limit.

Vacuum Structure and Confinement / 156

Effective string description of the interquark potential in the 3D U(1) Lattice Gauge Theory

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The U(1) lattice gauge theory in three dimensions is a perfect laboratory to study the subtle properties of the confining string. On the one hand, thanks to the mapping to a coulomb gas of monopoles, the model can be exactly solved and confinement proven analytically. On the other hand high-precision numerical estimates of Polyakov loop correlators can be obtained via a duality map to a spin model. This allowed us to perform high precision tests of the universal behaviour of the effective string and to find macroscopic deviations with respect to the expected Nambu-Goto predictions. These corrections could be fitted with very good precision by the addition of a contribution proportional to the square of the extrinsic curvature to the effective string action. Such a contribution is allowed by Lorentz invariance and its presence in the infrared regime of the U(1) model was indeed predicted by Polyakov several years ago.
Performing our analysis at different values of β we were able to
show that this term scales as expected by Polyakov's solution and becomes the dominant contribution in the continuum limit. We also discuss the interplay between the extrinsic curvature contribution and the boundary correction induced by the Polyakov loops.

Poster session - Board 28 / 157

Rho mesons in strong abelian magnetic field in SU(3) lattice gauge theory

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We calculated correlators of vector and pseudoscalar currents in external strong abelian magnetic field in SU(3) gluodynamics.
The masses of charged and neutral mesons with various spins were calculated. We found out that the masses of mesons with zero spin s=0 decreased in increasing magnetic field, but the masses of Rho mesons with nonzero spin increased in the field.

Physics beyond the standard model / 158

Last results of N=1 supersymmetric Yang-Mills theory with some topological insights

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We summarize the last results of our collaboration concerning
N=1 supersymmetric Yang-Mills theory in four dimensions on the lattice.
We investigate the expected formation of supersymmetric multiplets of the
lightest particles and the behaviour of the topological susceptibility
approaching the supersymmetric and the continuum limit of the theory.

Standard model parameters and renormalization / 159

A dynamical study of the chirally rotated Schrödinger functional in QCD

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The chirally rotated Schrödinger functional for Wilson quarks allows for finite-volume, mass-independent renormalization schemes compatible with automatic O(a)-improvement. So far, in QCD, the setup has only been studied in the quenched approximation. Here we present first results for Nf=2 dynamical flavors for several renormalization factors of quark bilinears. We discuss how such renormalization factors can be easily obtained from simple ratios of two-point functions, and show how automatic O(a)-improvement is at work. We then compare our results with previous Schrödinger functional determinations.

Nonzero temperature and Density / 160

Two-color QCD with chiral chemical potential

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We present preliminary results of the study lattice SU(2) QCD phase diagram with chiral chemical potential. The simulation is carried out with dynamical staggered fermions without rooting. The dependences of the chiral density, Polyakov loop, chiral condensate and corresponding susceptibilities on the chiral chemical potential and temperature are measured.

Chiral Symmetry / 161

Comparison of different lattice definitions of the topological charge

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We present a comparison of different definitions of the topological charge on the lattice, with 2 and 2+1+1 flavours of dynamical twisted mass fermions. We give detailed results at one lattice spacing and also show that the correlation between different definitions increases as one approaches the continuum limit. The investigated definitions are: index of the overlap Dirac operator, spectral projectors, fermionic from disconnected loops, spectral flow of the Hermitian Wilson-Dirac operator and field theoretic with different kinds of smoothing of gauge fields (HYP and APE smearings, gradient flow, cooling). We also show some results on the topological susceptibility.

Nonzero temperature and Density / 162

Recent results on the Equation of State of QCD

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I will review results for the Equation of State of QCD, in particular I will give an update on our calculation that includes a dynamical charm quark.

Chiral Symmetry / 163

Topological susceptibility from the Dirac spectrum and the Witten-Veneziano formula.

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We present our results for the topological susceptibility in the quenched case and attempt a non-perturbative test on the Witten-Veneziano formula. We perform a continuum limit extrapolation of the topological susceptibility computed using spectral projectors.
The physical situation of the quenched ensembles was matched to the maximally twisted mass dynamical simulations used to compute the masses of the pseudoscalar mesons. In addition we present a study of the topological charge using spectral projectors including HYP smearing.

Nonzero temperature and Density / 164

Deconfining temperatures in SO(N) and SU(N) gauge theories

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We present our current results for the deconfining temperatures in SO(N) gauge theories in 2+1 dimensions. SO(2N) theories may help us to understand QCD at finite chemical potential since there is a large-N orbifold equivalence between SO(2N) QCD-like theories and SU(N) QCD and SO(2N) theories do not have the sign problem present in QCD. We show that the deconfining temperatures in these two theories match at the large-N limit. We also present results for SO(2N+1) gauge theories and compare results for SO(6) with SU(4) gauge theories, which have the same Lie algebras but different centres.

Weak Decays and Matrix Elements / 165

Non-perturbative study of the chromagnetic operator on the lattice

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We describe our study of the chromomagnetic operator O_CM, which appears in the effective Hamiltonian describing DS=1 transitions in and beyond the Standard Model.
Having dimension 5, the chromomagnetic operator is characterized by a rich pattern of mixing with other operators of equal and lower dimensionality. We have computed the coefficients of the mixing with the various dimension 5 operators using one loop lattice perturbation theory and determined the power-divergent mixing coefficient with the scalar density non-perturbatively. The numerical computations have been carried out by using the gauge configurations produced by the European Twisted Mass Collaboration with Nf = 2 + 1 + 1 dynamical quarks, at three values of the lattice spacing and several values of the light quark masses.
In this talk, we will mainly describe the non-perturbative parts of the calculation and present preliminary results for the matrix element of the chromomagnetic operator between pion and kaon states.

Vacuum Structure and Confinement / 166

Confinement, the Abelian Decomposition, and the Contribution of Topology to the Static Quark Potential

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In the past few years, we have presented a new way of considering quark confinement. Through a careful choice of a Cho-Duan-Ge Abelian Decomposition, we can construct the QCD Wilson Loop in terms of an Abelian restricted field. The relationship between the QCD and restricted string tensions is exact; and we do not need to gauge fix, apply any path ordering of gauge links, or additional path integrals. This hints at why mesons are colour neutral.

Furthermore, the Abelian restricted field contains two parts: a Maxwell term, and a topological term. The topological term can describe magnetic monopoles and other topological objects, which can be studied both numerically and theoretically. By examining the topological part of the restricted field strength we have found evidence suggesting that these objects, which will contribute to confinement if present, are indeed there.

Previous studies have used simplifications, breaking the exact relationship between the restricted and QCD string tensions, but it was found that the topological term dominated the restricted string tension. Here we remove those simplifications, and show that the Abelian restricted field does indeed fully explain confinement. However, we find that the topological component of the restricted field only accounts for $\sim \frac{1}{3}$ of the static quark potential, meaning that the Maxwell term also has a large contribution to the string tension. We comment on this discrepancy.

Hadron spectroscopy and interaction / 167

Updated results from maximally twisted mass QCD at the physical point

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In this contribution, updated results from simulations by the European Twisted Mass Collaboration at the physical point using Wilson twisted mass fermions with a clover term are presented. We discuss results for the pseudoscalar decay constants f_K, f_D and f_{D_s} and the corresponding masses. In addition, we provide evidence for a largely reduced flavour symmetry breaking in the presence of a clover term.

Algorithms and Machines / 168

Coulomb and Landau Gauge Fixing in GPUs using CUDA and MILC

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In this work, we present the GPU implementation of the overrelaxation and steepest descent method with Fourier acceleration methods for Laudau and Coulomb gauge fixing using CUDA for SU(N) with N>2.
A multi-GPU implementation of the overrelaxation method is also presented using MPI and CUDA.
The GPU performance was measured on BlueWaters and compared against the gauge fixing of the CPU MILC code.

Hadron Structure / 169

Volume effects on the method of extracting form factors at zero momentum

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The Rome method allows one to extract form factors using lattice computations performed strictly at zero momentum. We investigate the size of finite volume effects resulting from this method. As a test case, we focus on the pion charge radius and show how to ascertain the finite volume effect with the aid of chiral perturbation theory. The framework developed can easily be generalized to account for modified infrared physics of other low-energy matrix elements extracted at zero momentum.

Nonzero temperature and Density / 170

The N_f=3 critical endpoint with smeared staggered quarks

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We present preliminary results for the determination of the critical
endpoint of the chiral transition in N_f=3 QCD with mu=0 at small N_t.
We have employed an unimproved Wilson gauge action with
staggered fermions, for which previous results on the critical endpoint are available.
As an extension of these results we have studied the dependence of the
critical mass on the strength of the smearing.

Theoretical Developments / 173

Tree level improvement of the gradient flow

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The Yang-Mills gradient flow is considered in lattice perturbation theory at leading order of the gauge coupling and O(a^8) in the lattice spacing. Improved actions are incorporated for the gauge action, the flow itself and the observable for E(t). The results lead to a setup with O(a^6) improvement at tree level.

Hadron spectroscopy and interaction / 174

Determining Sigma - Lambda mixing

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SU2 isospin breaking effects in hadron octet and decuplets
are due to a combination of up and down quark mass differences
and electromagnetic effects. Usually these masses difference are small.
Between the Sigma and Lambda the splitting is much larger
due to mixing between these states. We determine the QCD mixing matrix
and hence find the mixing angle and mass splitting. Provided
the average quark mass is kept constant, the expansion coefficients
in our procedure can be determined from computationally cheaper
simulations with mass degenerate sea quarks and partially quenched
valence quarks.

Poster session - Board 29 / 175

Critical behavior and continuum scaling of 3D Z(N) lattice gauge theories

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Three-dimensional Z(N) lattice gauge theories are studied numerically
at finite temperature for N = 5, 6, 8, 12, 13, 20 and for N_t=2,4,8.
For each model the location of phase transitions and their critical
indices are determined. The scaling of critical points with N is proposed.
The data obtained enable us to verify the scaling near the continuum limit
for the Z(N) models at finite temperatures.

Poster session - Board 30 / 176

Probing mesonic and diquark wavefunctions in two color QCD at non-zero baryon density

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The properties of the ground state of two-color QCD at non-zero baryon chemical potential mu present an interesting problem in strongly-interacting gauge theory; in particular the nature of the physically-relevant degrees of freedom in the superfluid phase
in the high-mu regime still needs clarification. In this study we present evidence for in-medium effects at high mu by studying the wave functions
of mesonic and diquark states using orthodox lattice simulation techniques, made possible by the absence of a Sign Problem for the model with Nf=2. Our results show that beyond onset the spatial extent of hadrons decreases with mu, and are consistent with the existence of a dynamically-gapped Fermi surface in this regime.

Theoretical Developments / 177

Hadron masses from fixed topological simulations: discussion of parity partners and SU(2) Yang-Mills results.

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Lattice QCD simulations tend to become stuck in a single topological sector at fine lattice spacing or when using chirally symmetric overlap quarks. In such cases physical observables differ from their full QCD counterparts by finite volume corrections, which need to be understood on a quantitative level. We discuss extensions of existing relations from the literature between correlation functions at fixed topology and hadron masses at unfixed topology. Particular focus is put on disentangling positive and negative parity states, which mix, when the topological charge is fixed. Numerical results are presented for SU(2) Yang-Mills Theory.

Nonzero temperature and Density / 178

The effective Polyakov loop theory for finite temperature Yang-Mills theory and QCD

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The effective Polyakov loop theory reproduces the main features of the
Yang-Mills theory and QCD at finite temperature. A systematic derivation of the effective theory is a combined strong coupling and hopping parameter expansion. It includes a systematic ordering principle of the effective couplings. I will review this approach as well as results and possible applications.
Furthermore, I will discuss how non-perturbative corrections to the
couplings can be derived from simulations of the full theory.

Theoretical Developments / 179

Topologically restricted measurements in lattice sigma-models

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We consider models with topological sectors and difficulties with their Monte Carlo simulation. In particular, we are concerned with the situation where a simulation has a very long auto-correlation time with respect to the topological charge. In such cases, reliable numerical measurements are only possible within single topological sectors. The challenge is to assemble such restricted measurements to obtain an approximation for the complete result, which corresponds to the correct sampling over the entire set of configurations. We show that under certain conditions this is indeed possible and additionally provides an estimate for the topological susceptibility chi_t. Based on the correlation of the topological charge density, the evaluation of chi_t might be feasible even from data in just one topological sector. Here we present numerical results for these techniques in the framework of non-linear sigma-models by using a cluster algorithm.

Standard model parameters and renormalization / 180

Renormalization constants for $N_{\rm f}=2+1+1$ twisted mass QCD

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We summarize recent non-perturbative results obtained for renormalization constants computed in the RI'-MOM scheme for $N_{\rm f}=2+1+1$ twisted mass QCD. Our implementation employs the Iwasaki gauge action and four dynamical degenerate twisted mass fermions. Renormalization constants for scalar, pseudo-scalar, vector and axial operators, as well as for the quark propagator, are computed at three different values of the lattice spacing, two different volumes and several values of the twisted mass. Our method allows for a precise cross-check of the running, because of the particular proper treatment of the hypercubic artifacts. Preliminary results for twist-2 operators are also presented.

Hadron spectroscopy and interaction / 181

Resonances in pi-K scattering

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We have obtained clear signals of resonances in coupled-channel pi K - eta K scattering. Using distillation and a large basis of operators we are able to extract a precise spectrum of energy levels using the variational method. These energies are analysed using inelastic extensions of the Luescher method to obtain scattering amplitudes that clearly describe S, P and D wave resonances, corresponding to the physical K_0^*(1430), the K^*(892) and the K_2^*(1430).

Physics beyond the standard model / 182

Nuclear physics beyond QCD

Dr. DETMOLD, William [1]; Dr. POCHINSKY, Andrew [1]; Dr. MCCULLOUGH, Matthew [1]

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We consider QCD-like, composite models of dark matter and investigate what role nuclear physics may play in the dark sector. We compute the multi-particle spectrum of SU(N_c=2) gauge theory with two fundamental fermions, finding strong evidence for the existence of bound multi-hadron systems (nuclei) in this theory. We briefly discuss the rich phenomenological consequences of such strong interaction dynamics.

Vacuum Structure and Confinement / 183

London penetration depth and coherence length of SU(3) vacuum flux tubes

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The transverse profile of the chromoelectric field generated by a quark-antiquark pair in the SU(3) vacuum is analysed within the dual superconductor scenario, then the London penetration depth and coherence length are extracted.
The color field is determined on the lattice through a connected correlator of two Polyakov loops measured on smeared configurations.

Weak Decays and Matrix Elements / 184

Standrad Model contributions to B and Bs meson semileptonic decays

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We present our recent results on B to D, Bs to Ds, and Bs to K Standard Model tree level semileptonic decays.
We have used MILC Nf=2+1 asqtad gauge configurations with two lattice spacings.
For the valence quarks, we used NRQCD bottom quarks and HISQ light and charm quarks.
The B to D and Bs to Ds semileptonic form factors can be used for better determination of the Bs to [mu^+ mu^-] branching fraction.
Furthermore the ratio R(D) of the B to [D, tau, nu] and B to [D, mu, nu] branching fractions is of considerable phenomenological interest since there currently exists some tension between experiment and Standard Model predictions for R(D).
The Bs to K semileptonic decay is a new channel at LHCb and Belle II for alternate V_{ub} determinations.
Our form factor results for this decay are the first from lattice QCD.

Hadron spectroscopy and interaction / 185

On the extraction of spectral quantities with open boundary conditions.

Mr. BRUNO, Mattia [1]; Prof. SOMMER, Rainer [1]; Dr. SCHAEFER, Stefan [1]; Dr. KORCYL, Piotr [1]; Dr. LOTTINI, Stefano [1]; Dr. KORZEC, Tomasz [2]

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We discuss methods to extract decay constants, meson masses and gluonic observables in the presence of open boundary conditions. Our CLS ensembles have 2+1 flavours of O(a)-improved Wilson fermions and are generated with a small twisted mass as proposed by Luescher and Palombi. We analyse the associated reweighting for different observables.

Theoretical Developments / 186

Optimisation of Quantum Evolution Algorithms

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A specific unitary evolution operator can be constructed in many different ways, corresponding to different Hamiltonian trajectories between the desired end-points. An optimal trajectory can then be selected to make the evolution have the best computational complexity and control over errors. Using Grover's quantum search algorithm as an explicit example, it is shown that the complexity has a power-law dependence on error when a straightforward Lie-Trotter formula is used, and it becomes logarithmic in error when reflection operators are used. The exponential change in error control is surprising, and can be used to improve importance sampling methods. The key concept is to make the evolution steps as large as possible while obeying the constraints of the problem. In particular, we can understand why overrelaxation algorithms are superior to small step size algorithms.

Vacuum Structure and Confinement / 187

Spectral Flow and Index Theorem for Staggered Fermions

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We investigate numerically the spectral flow introduced by Adams for the staggered Dirac operator on realistic quenched gauge configurations in 2D and 4D. We study both the unimproved and the HISQ Dirac operators, and we compare with the case of spectral flow for Wilson fermions. We show that the spectral flow provides a good topological definition of the index, with a clear separation of high and low crossing modes, especially for the HISQ Dirac operator.

Weak Decays and Matrix Elements / 188

Charm physics with Moebius Domain Wall Fermions

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We study the feasibility of using a novel discretisation (Moebius) to directly simulate charm physics within the Domain Wall formalism. We then present results for a range of physical quantities including meson masses as well as decay constants and the dispersion relation of heavy-heavy (eta_c) and heavy-strange (D_s) pseudoscalar mesons. Four extensive sets of tree-level Symanzik pure gauge ensembles with lattice spacing ranging 0.03-0.1fm allow us to perform a continuum limit of the above quantities in a controlled way. Our numerical studies aim to map out the range of simulation parameters where the properties of Domain Wall Fermions known from light quark physics persist.

Nonzero temperature and Density / 189

Quark number susceptibilities from fugacity expansion at finite chemical potential

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Generalized quark number susceptibilities have been proposed to be good probes for the phase transition in QCD and in the search of a critical point. In this work we explore the possibilities of the expansion in the fugacity parameter $e^{\mu\beta}$ which has features which make, in particular, quark number related bulk observables easily accessible. We will present results at finite chemical potential up to the 4th order of generalized susceptibilities, its ratios and comparisons to model calculations.

Hadron spectroscopy and interaction / 190

Pi-Pi Scattering with N_f=2+1+1 Twisted Mass Fermions

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Pi-Pi scattering is investigated for the first time for N_f=2+1+1
dynamical quark flavours using Wilson twisted mass fermions. Lüschers
finite size method is used to relate energy shifts in finite volume
to scattering quantities like the scattering length in the I=2
channel. The computation is performed at several pion masses and lattice
spacings utilysing the stochastic LapH method, which is applied to spatial lattice volumes as large as 48^3.

Vacuum Structure and Confinement / 191

two-dimensional phase structure of SU(2) gauge-Higgs model

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We study numerically the phase structure in two dimensions
with SU(2) gauge-Higgs coupling.
We calculate the static potential from Wilson Loop, W propagator
and the order parameter related to a transition between the confinement-like
phase and Higgs-like phase. Our results suggest that there
is a confinement-like phase and Higgs-like phase, even in two dimensions.
In the confinement-like phase, the static potential rises linearly with string breaking at large distances, while in the Higgs-like phase, it is of Yukawa
type, consistent with a Higgs-type mechanism. The correlation length
obtained from the W propagator has a maximum between these phase.

Nonzero temperature and Density / 192

A novel density of state method for complex action system

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Recently, a new and efficient algorithm (the LLR method) has been proposed for computing density of states in statistical systems and gauge theories. In this talk, we explore whether this novel density of state method can be applied to numerical computations of observables in systems for which the action is complex. To this purpose, we introduce a generalised density of states, in terms of which integrals of oscillating observables can be determined semi-analytically, and we define a strategy to compute it with the LLR method. As a case study, we apply these ideas to the Z(3) spin model at finite density, finding a remarkable agreement of our results for the phase factor with those obtained with the worm algorithm for all explored chemical potentials, including values for which there are cancellations over sixteen orders of magnitudes. These findings open new perspectives for dealing with the sign problem on physically more relevant systems.

Vacuum Structure and Confinement / 193

Z(N) dependence of the pure Yang-Mills gluon propagator in the Landau gauge near Tc

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The Z(N) dependence of the pure Yang-Mills gluon propagator, in the Landau gauge, is investigated at finite temperature for N=3. Special attention will be given to the behaviour near the critical temperature Tc. Our simulations show a complex pattern as expected in a first order phase transition. Furthermore, we identify an order parameter directly associated with the breaking of the SU(3) center symmetry.

Algorithms and Machines / 194

Extending the QUDA library with the EigCG solver

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Realization of the Incremental eigCG algorithm for solving Hermitian linear systems with multiple right hand sides on the CUDA platform is reported. In particular, we present details of implementation of the algorithm in the QUDA library. Preliminary performance results are provided.

Weak Decays and Matrix Elements / 195

Charmed and strange pseudoscalar meson decay constants from HISQ simulations

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We present final results for decay constants of charmed and strange pseudoscalar mesons, calculated on MILC ensembles with four dynamical quarks. The HISQ action is used for both the valence and sea quarks.
A straightforward analysis on the ensembles with physical quark masses, which avoids the need for chiral perturbation theory, is performed first.
We report the resulting values for quark mass ratios, as well as an update of our previous result for f_{K^+}/f_{π^+}.
We then fit the lattice data for heavy-light decay constants to expressions derived in staggered chiral perturbation theory.
The chiral analysis allows us to use all our data, including ensembles with unphysical sea-quark masses, as well as those with physical masses.
This approach makes it possible to achieve small statistical errors and good control of the systematic errors, with final errors at the sub-precent level.
A comparison with the results of the straightforward analysis on the physical-mass ensembles is included in the systematic error estimates.
We also present continuum-extrapolated results for the decay constants of charmed pseudoscalar mesons evaluated at various values
of the light sea-quark mass, which may be useful for normalizing other calculations performed at unphysical mass values.

Hadron Structure / 196

Electromagnetic matrix elements for excited Nucleons

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Over the past decade there has been significant experimental interest into the electromagnetic excitation of nucleon resonances and their underlying structure. Given the large body of data that now exists, it is interesting to consider the expectations presented by QCD. Correlation matrix techniques present us with the ideal approach to extracting matrix elements of hadronic excitations. Following our recent success in identifying the underlying structure of the Lambda(1405) using this approach, we now consider the nucleon sector. In this talk we shall outline the method and present first results for the low-lying nucleon excited state spectrum in the positive and negative parity channels.

Hadron spectroscopy and interaction / 197

Low lying charmonium states at the physical point

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We present results for the mass splittings of low-lying charmonium states from a calculation of Wilson clover quarks with the Fermilab interpretation on an asqtad sea. We use five lattice spacings and two values of the light sea quarks to extrapolate our results to the physical point. Sources of systematic uncertainty in our calculation are discussed and we compare our results for the 1S hyperfine splitting, the 1P-1S splitting and the P-wave spin orbit and tensor splittings to experiment.

Hadron Structure / 198

Calculation of disconnected contributions to nucleon form factors using hierarchical probing

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We present results for the disconnected contributions to light-quark nucleon form factors and generalized form factors at a pion mass of approximately 300 MeV. The calculations are performed with clover fermions in a large volume, and the disconnected quark loops are evaluated using the hierarchical probing method. We compare the behavior of hierarchical probing with the traditional noise method for a wide range of observables. A large reduction of variance is observed for the electromagnetic form factors. For these form factors, we are able to clearly resolve nonzero disconnected light-quark contributions for the first time. We find that the ratio of disconnected to connected contributions to the proton electromagnetic form factors is of order 0.5%.

Poster session - Board 31 / 199

Determination of the mass anomalous dimension for Nf=12 and Nf=9 SU(3) gauge theories

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We show the numerical simulation result for the mass anomalous dimension of the SU(3) gauge theory coupled to Nf = 12 fundamental fermions.
We use both the step scaling method and the hyperscaling for the Dirac eigenmode to determine the anomalous dimension in the vicinity of the infrared fixed point of the theory.
The continuum extrapolation is carefully taken in both analyses.
We also show our preliminary result of the anomalous dimension for Nf=9 case.

Nonzero temperature and Density / 200

Critical end point in Nf=3 QCD with finite density and temperature

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We investigate a presence of critical end point in finite density/temperature QCD with three-degenerated Wilson-Clover quarks. The critical end point is estimated by the kurtosis intersection method and a gap of transition points between two independent observables. We also discuss slope/curvature of the critical end line extending from the zero density point whose details will be given in a talk by Y.Nakamura.

Nonzero temperature and Density / 202

Update on the critical endpoint of the finite temperature phase transition for three flavor QCD with clover type fermions

Dr. NAKAMURA, Yoshifumi [1]; Dr. JIN, Xiao-yong [1]; Prof. KURAMASHI, Yoshinobu [2]; Dr. TAKEDA, Shinji [3]; Dr. UKAWA, Akira [1]

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We present preliminary results on the critical endpoint of
three flavor QCD at zero chemical potential.
We employ the renormalization-group improved Iwasaki gauge action
and $O(a)$-improved Wilson fermion action.
The critical endpoint is determined by using the intersection points
of kurtosis for mixed observable as well as plaquette, gange action density,
Polyakov loop and "chiral condensate" at the temporal size N_t=4, 6 and 8.

Chiral Symmetry / 203

The Chiral Condensate of One-Flavor QCD and the Dirac Spectrum at $\theta=0$

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In a sector of fixed topological charge, the chiral condensate has a discontinuty given by the Banks-Casher formula also in the case of one-flavor QCD. However, at fixed θ angle, the chiral condensate remains constant when the quark mass crosses zero. To reconcile these contradictory observations, we have evaluated the spectral density of one-flavor QCD at $\theta=0$. For negative quark mass, it becomes a strongly oscillating function with a period given by the inverse space-time volume and an amplitude that increases expoentially with the space-time volume. As we have learned from QCD at nonzero chemical potential, if this is the case, an alternative to the Banks-Casher formula applies, and we will demonstrate that for one-flavor QCD, this results into a continuous chiral condensate. A special role is played by the topological zero modes which have to be taken into account exactly in order to get a finite chiral condensate in the thermodynamic limit.

Hadron Structure / 204

A Feynman-Hellmann approach to the spin structure of hadrons

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By introducing an external spin operator to the fermion action, the quark-line connected matrix elements relevant for quark spin fractions of hadrons are extracted from the linear response of the hadron energies using the Feynman-Hellmann (FH) theorem. At the SU(3)-flavour symmetry point, we find that the connected quark spin fractions are universally in the range 55-70% for vector mesons and octet and decuplet baryons. There is an indication that the amount of spin suppression is quite sensitive to the strength of SU(3) breaking. Finally, I also hope to present preliminary results applying the FH technique to calculations of quark line disconnected contributions to hadronic matrix elements.

Nonzero temperature and Density / 205

Multipoint reweighting method and beta-functions for the calculation of QCD equation of state

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We discuss the reweighting method aiming numerical studies of QCD at finite density, in which the Monte-Carlo method cannot be applied directly. One of the most important problems in the reweighting method is the overlap problem. To solve the problem, we propose the following reweighting method: simulations are performed at several simulation points and the analysis is done combining all data. We explain the method and discuss the improvement of the overlap problem. As an application of the multipoint reweighting method, we compute the meson masses as continuous functions of beta and hopping parameters (kappa). Then, lines of constant physics in the (beta, kappa) space are determined, and the derivatives of the lattice spacing with respect to beta and kappa are calculated along the lines of constant physics, which are needed for the calculation of the equation of state.

Poster session - Board 32 / 206

Calculation of BSM Kaon B-parameters using improved staggered quarks in N_f = 2+1 QCD.

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We present results of the Kaon B-parameters calculated using the HYP-improved staggered quarks on the MILC asqtad lattices.
The perturbative matching is done at one-loop level.
We extrapolate the data to physical pion mass using the SU(2) staggered chiral perturbation theory.
After that, we simultaneously extrapolate results to the continuum (a = 0) and physical sea quark mass.
We report our final results evaluated at 2GeV and 3GeV in the $\overline{MS}$ scheme with naive dimensional regularization.
And we present error budgets for the B-parameters in the conclusion.
This work will lead to a series of constraint equations for the BSM models.

Physics beyond the standard model / 207

Results from lattice studies of maximally supersymmetric Yang--Mills

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I will present results from numerical lattice studies of maximally (N=4) supersymmetric Yang--Mills theory with gauge group SU(2), based on a lattice formulation that exactly preserves one supersymmetry. While the pfaffian of the lattice theory is not manifestly real, direct measurements of the pfaffian show it to be approximately real and positive on all accessible lattice volumes. Studies of the static potential show that the system exhibits coulombic behavior at both weak and strong coupling, with Coulomb coefficients in agreement with leading-order perturbation theory. In addition to these results, I will discuss ongoing studies of gauge groups SU(3) and SU(4), with which we aim to access the large-N limit.

Standard model parameters and renormalization / 210

Non-perturbative Renormalization of Four-fermion Operators Relevant to B_K with Staggered Quarks.

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We present matching factors for the four-fermion operators obtained using the non-perturbative renormalization method (NPR) in RI-MOM scheme for improved staggered fermions on the MILC asqtad lattice (N_f = 2+1).

Using 20^3 * 64 lattice (a = 0.12 fm, am_l/am_s = 0.01/0.05), we obtain the matching factor of B_K operator. Also we are in the middle of data analysis on the BSM operators.

These results will be used to obtain B_K and the BSM B-parameters.

We expect that the matching factor error obtained using NPR is in the level of ~2% which is much smaller than that of the one-loop perturbative matching (~4.4%).

We compare NPR results with those of one-loop perturbative matching.

Poster session - Board 33 / 211

Optimization of Lattice QCD Calculation on GTX Titan Black GPU and Xeon Phi Coprocessor

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There are new NVIDIA technologies, such as direct parallelism and GPU Direct, which reduce the communication time between GPUs and CPUs. NVIDIA Kepler GPUs also provide new features to improve the memory usage of CUDA codes which allows better performance in memory access, memory allocation, and deallocation. We optimize our conjugate gradient code for staggered quarks to obtain the full performance of the GTX Titan black GPU. We also apply various optimization schemes to the Xeon Phi coprocessor. One is the vectorization of the code by using 512-bit SIMD instructions which is essential to the programming on the Xeon Phi. The other is hybrid programming with MPI and OpenMP. In particular, in the case of OpenMP, threads can share the memory, which can, in principle, reduce the communication overload significantly.

Weak Decays and Matrix Elements / 212

Neutral B-meson mixing parameters in and beyond the SM with 2+1 flavor lattice QCD

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We present the status of our calculation of the hadronic matrix elements for neutral B-meson mixing with asqtad sea and valence light quarks and using the Wilson clover action with the Fermilab interpretation for the b quark. We calculate the matrix elements of all five local operators that contribute to neutral B-meson mixing both in and beyond the SM. Our analysis includes MILC asqtad ensembles at four different lattice spacings in the range a = 0.045-0.12 fm, and with light sea-quark masses as low as 0.05 times the physical strange quark mass. We perform a combined chiral-continuum extrapolation including the so-called wrong-spin contributions in simultaneous fits to the matrix elements of the five operators. Results for phenomenologically interesting quantities are presented with a complete systematic error budget.

Algorithms and Machines / 213

A filtering technique for the temporally reduced matrix of the Wilson fermion determinant

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The Wilson fermion determinant can be written in the form of a series expansion in fugacity z=exp(mu/T), provided that the eigenmodes of the temporally reduced operator are obtained. Since the calculation of all eigenmodes rapidly becomes prohibitive for larger volumes, we develop a method to calculate only the low-energy eigenmodes of the reduced matrix using a matrix filetering technique. This provides a basis of an approximation to neglect uninteresting ultraviolet contributions.

Nonzero temperature and Density / 214

Canonical approach to the finite density QCD with winding number expansion

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The canonical partition function is related to the grand canonical one through the fugacity expansion.
In this talk we perform the fugacity expansion by a method of the hopping parameter expansion in temporal direction: winding number expansion.
Since the convergence of our expansion is good only for a small κ we concentrate on heavy quark mass region.
For a numerical simulation we adopt the improved Wilson fermion with the APE stout smeared gauge links.
The grand canonical partition function is made for $N_f=2$ QCD in the imaginary chemical potential region including $\mu=0$.
After a derivation of the canonical partition function we study the Lee-Yang zeros of the complexified grand partition function.

Theoretical Developments / 215

String tension from smearing and Wilson flow methods

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Last year, we proposed a new method to extract string tension using 4-dimensional smearing method (PL B718 (2013) 1524). In this talk we first show that results using smearing method are equivalent to those obtained by Wilson flow once the time step \epsilon is sufficiently small. We then demonstrate the practical advantage of our method by applying it to the calculation of Creutz ratio in SU(3) Yang-Mills theory.

Standard model parameters and renormalization / 216

Nonperturbative renormalization of bilinear operators with Mobius domain-wall fermions in the coordinate space

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We study a non-perturbative determination of the renormalization constants of flavor non-singlet quark bilinear operators. The renormalization condition is imposed on correlation functions of bilinear operators in the coordinate space. The results are converted to the value in the MSbar scheme by a perturbative matching. The calculation is done on gauge configurations generated with the Mobius domain-wall fermions at two lattice spacings a = 0.08 and 0.06 fm.

Nonzero temperature and Density / 217

Renormalization group flow of linear sigma model with UA(1) anomaly

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Motivated by recent arguments on effective restoration of UA(1) symmetry around the critical temperature in two-flavor QCD, we investigate the renormalization group flow of the U(2)xU(2) linear sigma model (LSM) with the traditional epsilon expansion. Introducing the UA(1) violation, the attractive basin falling into the O(4) LSM in the parameter space and its dependence on the size of UA(1) violation are determined. Employing a mass-dependent renormalization scheme, we also look into how the theory with 8 degrees of freedom (U(2)xU(2) LSM) reduces the one with 4 (O(4) LSM).

Vacuum Structure and Confinement / 218

Partial restoration of chiral symmetry inside hadrons

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The presence of color source may modify the chiral condensate that characterizes the spontaneous breaking of chiral symmetry in the QCD vacuum. Using the overlap-Dirac eigenmodes, we investigate this phenomenon around static color sources representing quark-antiquark and three-quark systems. We show that the chiral condensate is reduced inside the flux-tube that is formed between the color sources. Using the three-quark system in a finite box, we estimate the magnitude of partial chiral restoration at finite density.

Nonzero temperature and Density / 220

Axial U(1) symmetry at finite temperature with Mobius domain-wall fermions

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Possible (effective) restoration of the axial U(1) symmetry at finite temperature has attracted a lot of attention in the last few years thanks to the development of the chiral lattice actions and algorithmic improvements. In our previous work we utilized the overlap fermion formulation to show an evidence for a restoration of the axial symmetry above the phase transition. In this work we address the systematics of the previous study by using the Mobius domain-wall fermions that allow for larger-scale simulations while maintaining excellent chiral properties. Different volumes and Ls, the fifth dimension controlling the chirality of the action, and lattice spacings are considered. We study the susceptibilities related to the axial U(1) symmetry, the screening masses, and the spectrum of the Dirac operator (see also A. Tomiya talk).

Hadron spectroscopy and interaction / 221

The Lambda 1405 is an anti-kaon--nucleon molecule

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For almost 50 years the structure of the Lambda(1405) resonance has been a mystery for particle physicists. Even though it contains a heavy strange quark and has odd parity its mass is lower than any other excited spin-1/2 baryon. Before the existence of quarks was confirmed, Dalitz and co-workers speculated that it might be a molecular state of an anti-kaon bound to a nucleon. Although the intervening years have seen considerable effort, there has been no convincing resolution. Here we demonstrate that a new lattice QCD simulation showing that its strange magnetic form factor vanishes, together with a comprehensive Hamiltonian effective field theory analysis of the lattice QCD energy levels, unambiguously establishes that the structure is dominated by a bound anti-kaon--nucleon component. This result clarifies that not all states occuring in Nature can be described within a simple quark model framework and establishes the existence of exotic molecular meson-nucleon bound states

Standard model parameters and renormalization / 222

Using NSPT for the Removal of Hypercubic Lattice Artifacts

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The quantification and subtraction of hypercubic lattice artifacts is essential for the calculation of non-perturbative renormalization constants. It has been shown that for the RI'-MOM scheme a large part of these artifacts can be calculated using Lattice Perturbation Theory (LPT), but these calculations are typically restricted to 1-loop order and to bilinear quark operators with one derivative at most.

With Numerical Stochastic Perturbation Theory (NSPT) one may overcome this limitation and calculate hypercubic corrections beyond 1-loop order, for any operator and action. In this study, we explore the practicability of this approach and consider, as a first test, the case of Wilson fermion bilinear operators in a quenched theory.

Chiral Symmetry / 223

Chiral condensate in nf=2 QCD from the Banks-Casher relation

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Exploiting the Banks-Casher relation, we present a direct determination of the chiral condensate in two-flavor QCD, computing the mode number of the O(a)-improved Wilson-Dirac operator below various cutoffs. We make use of CLS-configurations with three different lattice spacings in the range of 0.05-0.08 fm and pion masses down to 190 MeV. Our data indicates a finite density of eigenmodes near the origin and hence points to spontaneous chiral symmetry breaking. We extrapolate our results to the continuum and chiral limit to give a result for the chiral condensate.

Poster session - Board 34 / 224

Current status of ε_K calculated on the lattice

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We present results of ε_K, the indirect CP violation parameter calculated on the lattice combined with various inputs from the experiments. In this analysis we use the lattice results of B_K and V_{cb} for the exclusive channel. In addition, we also use Wolfenstein parameters from the CKM fitters and UT fitters. We find 3.4(3) σ difference in the exclusive V_{cb} channel. We report details of this result.

Poster session - Board 5 / 225

Lattice QCD code Bridge++ on multi-thread and many core accelerators

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We are developing a new code set ``Bridge++'' for lattice simulations.
It is aimed to be an extensible, readable, and portable workbench,
while it keeps a high performance. Bridge++ covers conventional
lattice actions and numerical algorithms. A recent massively parallel
cluster system requires a hybrid parallel programing, such as MPI and
OpenMP. We also need elaborated programing technique to
make use of arithmetic accelerators like GPGPUs and intel Xeon phi.
To control accelerator devices, we adopt OpenCL,
which provides APIs applicable to wide range of accelerators.
We report present status of multi-threading by OpenMP and
implementation for accelerator devices.

Weak Decays and Matrix Elements / 226

Scaling study of an improved fermion action on quenched lattices

Mr. CHO, Yong-Gwi [1]; Prof. HASHIMOTO, Shoji [2]; Dr. KANEKO, Takashi [2]; Dr. NOAKI, Jun-Ichi [2]; Dr. JUTTNER, Andreas [3]; Dr. MARINKOVIC, Marina [3]; Mr. TSANG, Justus [3]

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We present scaling studies for heavy-quark observables calculated with an O(a^2)-improved fermion action on tree-level Symanzik improved gauge configurations. Lattices of 1/a = 2.0-3.7 GeV with an equal physical volume ~1.6 fm are used. The results are compared with the standard domain-wall and naive Wilson fermions.

Theoretical Developments / 227

Update on staggered Wilson fermions

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An update on our ongoing research on staggered Wilson fermions (a 2-flavor staggered version of Wilson fermions) will be given. Previously we found that this formulation is 4-6 times more efficient than usual Wilson fermions for inverting the Dirac matrix in quenched backgrounds of a 16^3 x 32 lattice at beta=6. Further results for 20^3 x 40 lattices will be reported which reveal that the efficiency increases notably with decreasing lattice spacing at fixed physical volume and also increases slightly with increasing volume at fixed lattice spacing. Construction of meson (and baryon) operators for this formulation will also be described, and numerical results for the pseudoscalar meson spectrum will be presented if they are ready in time.

Physics beyond the standard model / 229

Scattering lengths in SU(2) Gauge Theory with two Fundamental Fermions

Dr. DRACH, Vincent [1]; Dr. HIETANEN, Ari [2]; Prof. PICA, Claudio [3]; Prof. SANNINO, Francesco [3]; Dr. ARTHUR, Rudy [3]

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We investigate non perturbatively scattering properties of Goldstone Bosons in SU(2) gauge theory with two Wilson fermions in the fundamental representation. Such a theory can be used to build extensions of the Standard Model that unifies Technicolor and pseudo Goldstone composite Higgs models. The leading order contribution to the scattering amplitude of Goldstone bosons at low energy is given by the scattering lengths. In the context of technicolor extensions of the Standard Model the scattering lengths are constrained by WW scattering measurements.
We first describe our setup and in particular the expected chiral symmetry breaking pattern.
We then discuss how to compute them on a lattice and give preliminary results using finite size methods.

Application beyond QCD / 230

The electro weak transition and the equation of state in the SU(2)-Higgs-model

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Since the discovery of the Higgs particle at the LHC it is possible to investigate the equation of state for the electro weak transition in the SU(2)-Higgs-model at physical parameters. We will present a line of constant physics and preliminary results on the equation of state for small Nt values. The data was obtained by simulation with a combined heatbath and overrelaxation algorithm.

Nonzero temperature and Density / 231

Scalar correlators near the 3-flavor thermal critical point

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We investigate screening masses at finite temperatures with 3 flavors using the non-perturbatively improved clover fermion action and the Iwasaki gauge action. This report focuses on the behavior of the scalar singlet correlator near the thermal critical point. I will explain the technique used to extract the correlator and discuss our preliminary results from ensembles at Nt=8.

Nonzero temperature and Density / 232

Charmonium spectra and dispersion relation with improved Bayesian analysis in lattice QCD

Mr. IKEDA, Atsuro [1]; Prof. ASAKAWA, Masayuki [1]; Prof. KITAZAWA, Masakiyo [1]

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We study the charmonium property at finite temperature and finite momentum in
quenched lattice QCD with improved maximum entropy method (MEM).
We extend the MEM analysis to the product space of the correlation functions at more
than two different momenta to take advantage of more data and the strong
correlation among Euclidean correlators with different momenta.
We find that this method drastically improves the error of
the reconstructed spectral images.
We apply this method to analyze the dispersion relation of charmonia at finite temperature.

Physics beyond the standard model / 233

The low mass scalar impostor and the composite Higgs

Mr. WONG, chik him [1]; Dr. NOGRADI, Daniel [2]; Prof. KUTI, Julius [1]; Prof. HOLLAND, Kieran [3]; Prof. FODOR, zoltan [4]; Dr. MONDAL, Santanu [2]

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The widely discussed near-conformal gauge theory with two fermion flavors in the two index symmetric (sextet) representation of the SU(3) color gauge group is the minimal realization of the composite Higgs mechanism. A comprehensive study of flavor singlet scalar spectroscopy with Higgs quantum numbers is reported based on extended new data sets.

Theoretical Developments / 234

Temperature dependence of the chiral condensate in the Schwinger model with Matrix Product States

Dr. SAITO, Hana [1]; Dr. BANULS, Mari Carmen [2]; Dr. CICHY, Krzysztof [1]; Dr. CIRAC, J. Ignacio [2]; Dr. JANSEN, Karl [1]

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Tensor network methods form a family of efficient techniques of approximating quantum states. Their successes in quantum many-body physics have inspired their use for lattice gauge theories. We employed one of the tensor network techniques, called Matrix Product States, to investigate the Schwinger model in the Hamiltonian formulation. In this talk, we show our results for the temperature dependence of the chiral condensate in the massless model and we compare to the analytical formula derived by Sachs and Wipf.

Hadron spectroscopy and interaction / 235

Charm in Lattice QCD with Domain-Wall Fermion

Prof. CHIU, Ting-Wai [1]; Dr. HSIEH, Tung-Han [2]; Dr. CHEN, Yu-Chih [1]

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We study the charm physics in two-flavors lattice QCD with optimal domain-wall fermion. The gauge ensembles are generated on the $24^3 \times 48 $ lattice with the extent in the fifth dimension $ N_s = 16 $, and the plaquette gauge action at $ \beta = 6.10 $,
for three sea-quark masses corresponding to the pion masses in the range 265-465 MeV. We determine the lattice spacing by the Wilson flow, and the strange and the charm quark masses
by the masses of the vector mesons $ \phi(1020) $ and $ J/\psi(3097) $ respectively. We compute the point-to-point quark propagators and measure the time-correlation functions of all 2-quark meson interpolators, and determine the lowest-lying mass spectra of charmed mesons with quark contents c-cbar, c-sbar and c-dbar. Moreover, we determine the pseudoscalar decay constants $ f_K $, $ f_D $ and $ f_{D_s} $, which are in good agreement with the experimental values.

Hadron spectroscopy and interaction / 236

Hadron spectra and Delta_mix from overlap quarks on a HISQ sea.

Dr. LYTLE, Andrew [1]; Dr. BASAK, Subhasish [2]; Dr. DATTA, Saumen [3]; Dr. MADANAGOPALAN, Padmanath [4]; Dr. MATHUR, Nilmani [1]; Dr. MAJUMDAR, Pushan [5]

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We present results of our continuing study on mixed-action hadron spectra and decay constants using overlap valence quarks on MILC's 2+1+1 flavor HISQ gauge configurations. This study is carried out on three lattice spacings, with charm and strange masses tuned to their physical values, and with m_l/m_s = 1/5. I will discuss a determination of the mixed-action parameter Delta_mix, which enters into chiral formulae for the masses and decay constants.

Standard model parameters and renormalization / 237

A perturbative study of the chirally rotated Schrödinger functional in QCD

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The chirally rotated Schrödinger functional renders the mechanism of automatic O(a) improvement compatible with the Schrödinger functional (SF) formulation. We here report on the determination to 1-loop order in perturbation theory of the renormalization coefficients necessary to achieve automatic O(a) improvement and the boundary improvement coefficients needed to eliminate the extra boundary O(a) effects present in any SF formulation.
After this is done, we perform a set of tests of automatic O(a) improvement and of the universality between standard and chirally rotated SF formulations.
Finally we discuss the determination of the non-singlet current renormalization constants ZA and ZV from ratios of 2-point functions in the chirally rotated setup.

Nonzero temperature and Density / 238

The density of states from first principles

Dr. PELLEGRINI, Roberto [1]; Prof. LUCINI, Biagio [1]; Prof. LANGFELD, Kurt [2]; Dr. RAGO, Antonio [2]

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We present a novel algorithm to compute the density of states, which is proven to converge to the correct result.
The algorithm is very general and can be applied to a wide range of models, in the frameworks of statistical mechanics and lattice gauge theory.
All the thermal or quantum expectation values can then be obtained by a simple integration of the density of states.
As an application, a numerical study of 4d U(1) compact lattice gauge theory is presented.

Theoretical Developments / 239

Topology density correlator on dynamical domain-wall ensembles with nearly frozen topological charge

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Global topological charge tends to decorrelate very slowly or to even freeze on fine lattice simulations, while local topological fluctuations are expected to survive and lead to correct physical results as long as the volume is large enough. We investigate this issue on the recently generated configurations including dynamical domain-wall fermions at a=0.08 fm and finer. We utilize the Yang-Mills gradient flow to define the topological charge density operator and calculate its long-distance correlation.

Nonzero temperature and Density / 240

Fluctuations of the electric charge in theory and experiment

Dr. BORSANYI, Szabolcs [1]; Dr. KRIEG, Stefan [2]; Prof. KATZ, Sandor D [3]; Prof. FODOR, Zoltán [1]; Prof. SZABÓ, Kálmán K [4]; Dr. RATTI, Claudia [5]

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We present the continuum extrapolated kurtosis, skewness and variance of the electric charge in a grand canonical ensemble with zero or small chemical potential. This observable his a particular relevance in Heavy Ion Physics since ratios of such fluctuations have been measured in experiment at the chemical freeze-out. We discuss how lattice results describe the STAR fluctuation data at RHIC and show a thermometer candidate for the LHC.

Nonzero temperature and Density / 242

Mesonic spectral functions and transport properties in the quenched QCD continuum

Mr. MEYER, Florian [1]; KACZMAREK, Olaf [2]

[1] University of Bielefeld, Germany

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We present new results on the reconstruction of mesonic spectral functions for three temperatures above T_c in quenched QCD. Making use of Clover improved Wilson valence quarks allows for a clean extrapolation of correlator data to the continuum. For the case of vanishing momentum the spectral function is obtained by fitting the data to a well motivated ansatz. In the vector channel for light quarks the electrical conductivity of the hot medium, related to the origin of the spectral function at zero momentum, is computed from the resulting parameters at all three temperatures.

Weak Decays and Matrix Elements / 243

Calculation of $K \to \pi\pi$ decay amplitudes with improved Wilson fermion in 2+1 flavor lattice QCD

Dr. ISHIZUKA, Naruhito [1]; Dr. ISHIKAWA, Ken-Ichi [2]; Dr. YOSHIE, Tomoteru [1]; Dr. UKAWA, Akira [3]

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We presnet our results of the $K\to\pi\pi$ decay amplitudes
for both the $\Delta I=1/2$ and $3/2$ channels.
Calculations are carried out with $N_f=2+1$ gauge configurations
previously generated by the PACS-CS Collaboration
with the Iwasaki gauge action and nonperturbatively
$O(a)$-improved Wilson fermion
at $a=0.091\,{\rm fm}$ and $m_\pi=280\,{\rm MeV}$
on a $32^3\times 64$ ($La=2.9 {\rm fm}$) lattice.

For the calculation of quark loop at the weak operator
in the disconnected diagram,
we use the stochastic method with the hopping parameter expansion technique
and the truncated solver method proposed by Bali et al..
We find that these are very efficient methods.

Hadron spectroscopy and interaction / 244

Quark mass dependence of three-nucleon forces in lattice QCD

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Recently, the determination of three-nucleon forces attracts a great deal of interest in light of their role in nuclear and astrophysical phenomena such as
EoS of nuclear matter and the structure of the neutron star core. In this talk, we present the lattice QCD calculation of three-nucleon forces utilizing the time-dependent HAL QCD method. In particular, we study the quark mass dependence of three-nucleon forces from lattice simulations with Nf=2 clover fermion action at m(pi) = 0.76, 0.93, 1.13 GeV.

Hadron Structure / 246

Nucleon electromagnetic form factors from twisted mass lattice QCD

Dr. ABDEL-REHIM, Abdou [1]; Prof. ALEXANDROU, Constantia [2]; Dr. CONSTANTINOU, Martha [3]; Dr. JANSEN, Karl [4]; Dr. KOUTSOU, Giannis [1]

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[2] University of Cyprus and The Cyprus Institute

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The electromagnetic form factors of the nucleon using twisted mass fermion configurations simulated by the ETM collaboration are presented. These include a gauge field ensemble simulated with two degenerate light quarks yielding a pion mass of around 130 MeV, as well as two ensembles yielding pion masses of 210 MeV and 370 MeV with additional strange and charm sea quarks tuned to their physical mass values. Details of the methods used and systematic errors are discussed, such as noise reduction techniques and the effect of excited state contamination.

Poster session - Board 47 / 247

Lepton anomalous magnetic moments from N_f=2+1+1 twisted mass fermions and N_f=2 twisted mass fermions at the physical point

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We present our results for the electron, the muon, and the tau anomalous magnetic moments obtained with four dynamical quarks.
Performing the continuum limit and an analysis of systematic effects, full agreement with phenomenological results is seen.
Additionally, the light quark contributions on the four-flavour sea are compared to the values obtained for N_f=2
physically light quarks. In the latter case different methods to fit the hadronic vacuum polarisation function are tested.

Chiral Symmetry / 248

Chiral Properties of Pseudoscalar Meson in Lattice QCD with Domain-Wall Fermion

Prof. CHIU, Ting-Wai [1]; Dr. HSIEH, Tung-Han [2]; Dr. CHEN, Yu-Chih [1]

[1] National Taiwan University

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We study the chiral properties of the pseudoscalar meson in 2-flavors lattice QCD with optimal domain-wall fermion. The gauge ensembles are generated on the $ 24^3 \times 48 $ lattice with the extent in the fifth dimension $ N_s = 16 $, and the plaquette gauge action at $ \beta = 6.10 $, for three sea-quark masses corresponding to the pion masses in the range 265-465 MeV. We calculate the mass and the decay constant of the pseudoscalar meson, and compare our data with the chiral perturbation theory (ChPT). We find that our data is in good agreement with the sea-quark mass dependence predicted by the next-to-leading order (NLO) ChPT, and provides a determination of the low-energy constants $ \bar{l}_3 $ and $ \bar{l}_4 $, the pion decay constant, the chiral condensate, and the average up and down quark mass.

Poster session - Board 50 / 249

Test of the Standard Model description of rare B decays using lattice QCD form factors

Dr. WINGATE, Matthew [1]; LIU, Zhaofeng [2]; Prof. HORGAN, Ronald [1]; Dr. MEINEL, Stefan [3]

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This poster reviews our recent calculation of $B \to K^*$, $B_s \to \phi$, and $B_s \to K^*$ form factors using nonrelativistic heavy quarks and improved staggered quarks on MILC lattices. These unquenched calculations, performed in the low-recoil kinematic regime, provide a significant improvement over the use of extrapolated light cone sum rule results. We use the form factors along with Standard Model determinations of Wilson coefficients to give theoretical results for several observables. Noting that the experimental measurements for the $B^0 \to K^{*0} \mu^+ \mu^-$ and $B_s \to \phi \mu^+ \mu^-$ branching fractions are smaller at low-recoil than the Standard Model predictions, we perform a fit of the relevant Wilson coefficients using experimental and lattice results. The favored values hint at deviations from the Standard Model that are consistent with fits done by other authors using complementary theoretical and experimental inputs.

Poster session - Board 12 / 250

CL2QCD - Lattice QCD based on OpenCL

Mr. SCIARRA, Alessandro [1]; Mr. PINKE, Christopher [2]; Prof. PHILIPSEN, Owe [3]; Mr. BACH, Matthias [4]

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In recent years it has been shown that Lattice QCD (LQCD) can benefit enormously from Graphic Processing Units (GPUs), which are well suited for memory bandwidth limited applications. Accordingly, the usage of GPUs in LQCD simulations is still expanding,
mainly relying on CUDA, applicable to NVIDIA hardware only. A hardware vendor independent approach is given by the Open Computing Language (OpenCL).

We present CL2QCD, a LQCD software based on OpenCL, which has been successfully used for non-zero temperature studies on AMD based clusters. While all mathematical operations are performed in OpenCL, the program logic and the hardware management is carried out in C++. This allows for a clear separation of concerns and, in particular, for a clear distinction of high and low level functionality. Several physical applications have been developed, in this contribution we will focus on the HMC implementation for Wilson and twisted mass Wilson fermions as well as the RHMC for staggered fermions and their performance. In addition we will delve into the concept of unit tests and how it can be applied to LQCD.

Poster session - Board 11 / 251

CL2QCD - Lattice QCD based on OpenCL

Mr. PINKE, Christopher [1]; Mr. SCIARRA, Alessandro [2]; Prof. PHILIPSEN, Owe [2]; Mr. BACH, Matthias [3]

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In recent years it has been shown that Lattice QCD (LQCD) can benefit enormously from Graphic Processing Units (GPUs), which are well suited for memory bandwidth limited applications. Accordingly, the usage of GPUs in LQCD simulations is still expanding,
mainly relying on CUDA, applicable to NVIDIA hardware only. A hardware vendor independent approach is given by the Open Computing Language (OpenCL).

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Nonzero temperature and Density / 252

Complex Langevin dynamics for SU(3) gauge theory in the presence of a theta term

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Recently progress has been made in applying complex Langevin dynamics to nonabelian gauge theories with a sign problem. Here we study the SU(3) gauge theory with a theta therm and present results at real theta.

Vacuum Structure and Confinement / 253

On the rigid string contribution to the interquark potential

Dr. CASELLE, michele [1]; Mr. VADACCHINO, Davide [2]; Dr. PELLEGRINI, Roberto [3]; Dr. PANERO, Marco [4]

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One of the most interesting recent results on the effective string description of Lattice Gauge Theories is the universality of the first few terms of the effective action. This is a direct consequence of the Lorentz invariance of the underlying LGTs and makes this theory much more predictive than usual effective models in particle physics.
Besides the well known Nambu-Goto action, one of the combinations allowed by Lorentz symmetry is the so called "rigid string" proposed more that 30 years ago by Kleinert and Polyakov as a candidate to explain confinement in the framework of the dual superconductor scenario.
In this talk we discuss a few non trivial properties of this string and evaluate, using the zeta function regularization, the corrections to the interquark potential induced by the extrinsic curvature term contained in the action.
We then compare our predictions with a set of high precision simulations of the 3d U(1) LGT and show that the large β behavior of the interquark potential is described very well by the rigid string. More precisely we observe, as β increases, a smooth cross-over from the usual Nambu-Goto behavior to a rigid string behavior which dominates in the continuum limit.
We finally discuss the implications of our results for SU(N) LGTs both in $d=3$ and in $d=4$.

Theoretical Developments / 254

Lattice study on diquark properties

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Two point functions of diquarks are calculated in the Landau gauge on the lattice with overlap fermions on 2+1-flavor domain wall fermion configurations. Masses of diquarks with spin 0 and 1 in the color anti-triplet representation are extracted. Pion mass dependence of the mass difference between the bad and good diquarks are studied.

Poster session - Board 17 / 255

Neutral B-meson mixing with physical u, d, s, and c sea quarks

Prof. DAVIES, Christine [1]; Dr. DOWDALL, Rachel [2]; Prof. HORGAN, Ron [2]; Prof. LEPAGE, Peter [3]; Dr. MONAHAN, Chris [4]; Prof. SHIGEMITSU, Junko [5]

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HPQCD Collaboration: We will present the first lattice QCD calculation of the mixing parameters f_B\sqrt(B_B) and f_B_s\sqrt(B_B_s) for physical light quark masses. We use 2+1+1 MILC configurations at 3 values of the lattice spacing and with three u/d quark masses going down to the physical value. We use improved NRQCD for the b quarks.

Hadron spectroscopy and interaction / 256

Comparison between two-quark, tetra-quark and molecular states of the sigma meson from lattice QCD

Mr. WAKAYAMA, Masayuki [1]; Prof. KUNIHIRO, Teiji [2]; Prof. MUROYA, Shin [3]; Prof. NAKAMURA, Atsushi [4]; Prof. NONAKA, Chiho [5]; Prof. SEKIGUCHI, Motoo [6]; Dr. WADA, Hiroaki [6]

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Our purpose is to obtain insights of structure of the sigma meson from lattice QCD. At present we do not reach a conclusive understanding of nature of the sigma meson. Currently it is considered as a usual two-quark state, four-quark states such as a tetra-quark and mesonic molecules or superposition of them. At present we do not reach a conclusive understanding of nature of the sigma meson. Besides, the mixing with glueballs is one of important and interesting ingredients for structure of the sigma meson. Furthermore, a disconnected diagram of the sigma meson plays an important role in the structure of the sigma meson. However, to evaluate the disconnected part of the propagator is not an easy task in lattice QCD calculation. To compute the disconnected part of the propagator, we use the Z2 noise method with the truncated eigenmode acceleration and the time dilution for estimating the all-to-all quark propagators. Here, we compare between two-quark, tetra-quark and molecular states in the sigma meson. An advantage state in the sigma meson will be discussed.

Poster session - Board 36 / 257

Light glueball masses using multilevel algorithm

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Following the multilevel scheme we present an error reduction algorithm for extracting glueball masses from monte-carlo simulations of pure SU(3)
lattice gauge theory. We look at the two lightest states viz. the 0^{++}
and 2^{++}. Our method involves looking at correlations between large wilson loops and does not require any smearing of links. The error bars we obtain are at the moment comparable to those obtained using smeared operators. We also present a comparison of our method with the naive method.

Hadron spectroscopy and interaction / 258

Heavy Meson Spectrum Tests of the Oktay-Kronfeld Action

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To achieve smaller heavy-quark discretization errors, the OK action was proposed as an improvement of the Fermilab action. The OK action includes the dimension 6 and 7 operators necessary for tree-level matching to QCD through order 1/m_Q^3 for heavy-light mesons and v^6 for quarkonium. To assess the improvement, we extend previous numerical tests with heavy meson masses by analyzing data generated on a finer lattice with the correct tadpole factors for the c_5 term in the action. We update the analyses of the hyperfine splittings for the rest and kinetic masses and the inconsistency parameter I.

Nonzero temperature and Density / 259

Exploring the phase diagram of QCD with complex Langevin simulations

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Simulations with a finite chemical potential typically lead to a severe sign problem, prohibiting any standard Monte Carlo approach. For simulations of QCD we use the complex Langevin method, for which we apply adaptive step-sizes and gauge cooling to ensure the convergence. We present preliminary results for heavy quark QCD and explore the application for two dynamical quarks.

Algorithms and Machines / 260

CLS 2+1 flavor simulations

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We report on the status of large volume simulations with 2+1 dynamical quarks which are being performed by the CLS collaboration. The algorithmic details include: open boundary conditions, twisted mass reweighting and the rational approximation for the strange quark, whereas the main feature of the simulation strategy is the approach to the physical point along a trajectory of constant trace of the mass matrix. We comment on the practical side of the above issues using as examples some of the newly generated ensembles, which presently cover lattice spacings between 0.11 fm and 0.05 fm and pion masses between 415 MeV and 150 MeV.

Hadron spectroscopy and interaction / 261

An improved study of the excited radiative decay $\Upsilon(2S) \to \eta_b(1S)\gamma$ using lattice NRQCD

Mr. HUGHES, Ciaran [1]; Dr. DOWDALL, Rachel [1]; Dr. M. VON HIPPEL, Georg [2]; Prof. R. HORGAN, Ronald [1]; Dr. WINGATE, Matthew [1]

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Recently Lewis and Woloshyn's exploratory study using lattice NRQCD to study the radiative decay $\Upsilon(2S) \to \eta_b(1S) \gamma$ found that next-to-leading order (v^6) contributions were large compared to the leading order (v^4) result. We explain this suppression of the v^4 term using a simple potential model. We then present our lattice QCD results obtained with three lattice spacings and high statistics. We employ improved actions, twisted boundary conditions, 1-loop perturbative matching, and Bayesian fitting methods. We conclude that lattice NRQCD can be used to
accurately calculate this and other radiative bottomonium decay rates.

Nonzero temperature and Density / 262

Understanding localisation in QCD through an Ising-Anderson model

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Above the QCD chiral crossover temperature, the low-lying eigenmodes of the Dirac operator are localised, while moving up in the spectrum states become extended. This localisation/delocalisation transition has been shown to be a genuine second-order phase transition, in the same universality class as that of the 3D Anderson model. The existence of localised modes and the effective dimensional reduction can be tentatively explained as a consequence of local fluctuations of the Polyakov loop, that provide 3D on-site disorder, in analogy to the on-site disorder of the Anderson model. To test the viability of this explanation we study a 3D effective, Anderson-like model, with on-site disorder provided by the spins of an Ising model, which mimics the Polyakov loop dynamics. Our preliminary results show that localised modes are present in the ordered phase, thus supporting the proposed mechanism for localisation in QCD.

Poster session - Board 46 / 263

Numerical investigations of Supersymmetric Yang-Mills Quantum Mechanics with 4 supercharges

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We report on our non-perturbative investigations of Supersymmetric Yang-Mills Quantum Mechanics with four supercharges. We employed two independent numerical methods. As a first method we used the cut Fock space approach in which one constructs the Hamiltonian matrix in an approximated basis of the Hilbert space and diagonalize it numerically to obtain the energy spectrum. As a second method we implemented the Rational Hybrid Monte Carlo algorithm which allowed us to study our system from a complementary perspective. We present a comparison of results obtained by the two methods for the models with SU(2) and SU(3) gauge groups, focusing on the low-energy part of the spectrum and on the structure of the ground states.

Hadron Structure / 264

News from hadron structure calculations with twisted mass fermions

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We report on the ongoing calculations of the European Twisten Mass Collaboration concerning the non-perturbative study of hadron structure. We discuss the status of these computations at the examples of various moments of parton distribution functions and give an update about the calculations for x_g and the full quark PDF of the nucleon.

Poster session - Board 49 / 265

Dual simulation of finite density lattice QED at large mass

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Using hopping expansion techniques we discuss a partial mapping of finite density lattice QCD to dual variables. After truncation the partition sum has only real and positive contributions also at arbitrary chemical potential, and a Monte Carlo simulation is possible. We discuss the algebraic aspects of the dualization and show some first numerical results.

Hadron spectroscopy and interaction / 266

Search for Z_c(3900) on the lattice with twisted mass fermions

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Recently a charged resonance-like structure $Z_c(3900)$ has been observed in several experiments. The invariant mass of this structure is close to the DD* threshold, and one possible interpretation is a molecular bound state formed by the D and $\bar{D}*$ mesons. We study the low-energy scattering of $D\bar{D}^*$ using lattice QCD with N_f = 2 twisted mass fermion configurations with three pion mass values. The threshold scattering parameters, namely the scattering length a_0 and effective range r_0, for the s-wave scattering in $J^P = 1^+$ channel are extracted. Our results indicate that the interaction of this channel is weakly repulsive. To further investigate the properties of $Z_c(3900)$, we redo the calculation with some improvements. We employ the stochastic LapH smearing method, which greatly improves the precision of our results. We also enlarge the operator basis and study the coupled channel effects.

Hadron Structure / 267

The strange and charm quark contributions to the anomalous magnetic moment (g -2) of the muon from current-current correlators

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We describe a new technique (presented in arXiv:1403.1778) to determine the contribution to the anomalous magnetic moment (g-2) of the muon coming from the hadronic vacuum polarization using lattice QCD. Our method uses Padé approximants to reconstruct the Adler function from its derivatives at q^2=0. These are obtained simply and accurately from time-moments of the vector current-current correlator at zero spatial momentum. We test the method using strange quark correlators calculated on MILC Collaboration's n_f = 2+1+1 HISQ ensembles at multiple values of the lattice spacing, multiple volumes and multiple light sea quark masses (including physical pion mass configurations).

Standard model parameters and renormalization / 268

Determination of \(c_{\rm sw}\) in \(N_f=3+1\) Lattice QCD with massive Wilson fermions

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We develop a strategy for the non-perturbative determination of the O(\(a\))-improvement coefficient \(c_{\rm sw}\) for Wilson fermions with massive sea quarks. The improvement condition is defined via the PCAC relation in the Schrödinger functional. It is imposed along a line of constant physics designed to be close to the correct mass of the charm quark. The numerical work uses the tree-level improved Lüscher-Weisz gauge action in \(N_f=3+1\) Lattice QCD.

Poster session - Board 45 / 269

The onset of the baryonic density in HD-QCD at low temperature

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We use the heavy dense approximation of QCD (HD-QCD) at
next-to-leading order (NLO) in the hopping expansion, keeping the
full Yang-Mills action. We perform simulations at low temperatures,
in the region below 1/3 T_c(\mu=0), and at large \mu, \mu/T above 5.
We analyse the structure in the baryonic density and other quantities
at the onset. We present data from reweighting (RW) and complex Langevin
equation (CLE) calculations for 2 flavours of Wilson fermions, and
discuss the results.

Algorithms and Machines / 270

Staggered Dslash Performance on Intel Xeon Phi Architecture

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The conjugate gradient algorithm is among the most essential and time consuming parts of lattice calculations with staggered quarks. We test the performance of dslash, the key step in the CG algorithm, on the Intel Xeon Phi, also known as the many integrated cores (MIC) architecture, with different parallelization strategies using MPI,OpenMP, and the vector processing units (VPUs).

Poster session - Board 19 / 271

Baryon resonances coupled to Pion-Nucleon states in lattice QCD

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In recent years the study of two particle systems on the lattice has led to excellent results in the meson sector of the QCD spectrum, however baryon resonances remain mostly unexplored.
We present an initial study of pion-nucleon systems as decay product of baryon resonances in different channels. The final goal is to extract the resonance parameters from the correlation functions of multi-particle interpolators. All the Wick contributions have to be explicitly evaluated and the consequences of broken symmetries in moving frames are taken into account. We discuss the theoretical setup together with some preliminary results of our trial simulations for nf=2 mass degenerate light quarks.

Physics beyond the standard model / 272

Light composite scalar and other spectra in Nf=8 QCD

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We (LatKMI Collaboration) present the first observation of a flavor-singlet scalar meson as light as the pion in Nf=8 QCD on the lattice, using the HISQ action. Such a light scalar meson can be regarded as a composite Higgs with mass 125 GeV, and may be a technidilaton, a pseudo Nambu-Goldstone boson of the approximate scale symmetry in walking technicolor.
We also report the update about the chiral behavior of other spectra, particularly the pion and the rho meson masses, the pion decay constant and the chiral condensate, in order to test walking signals in Nf=8 QCD.

Nonzero temperature and Density / 273

Effective SU(2) Polyakov Loop Theories with Heavy Quarks on the Lattice

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We compare SU(2) Polyakov loop models with different actions with data from full two-color QCD simulations around and above the critical Temperature [1,2].
We then apply the effective theory at finite temperature and density to
extract quantities like Polyakov loop correlators, effective Polyakov loop potentials and baryon density.

[1] Smith et al. , Phys. Rev. D88 (2013) 054020
[2] Scheffler et al. , arXiv: 1311.4324

Chiral Symmetry / 274

Fine lattice simulations with the Ginsparg-Wilson fermions

Dr. NOAKI, Junichi [1]; Prof. AOKI, Sinya [2]; Dr. COSSU, Guido [1]; FUKAYA, Hidenori [3]; Prof. HASHIMOTO, Shoji [1]; KANEKO, Takashi [1]

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We report the status of 2+1-flavor simulations with the Mobius domain-wall fermions on fine lattices of 1/a = 2.4 and 3.6 GeV. The violation of the Ginsparg-Wilson relation is controlled at the level of 0.5 MeV or better. Analyses of the Wilson flow observables, heavy quark potential and light-hadron correlator are presented.

Hadron Structure / 275

Systematics analyses on nucleon isovector observables in 2+1-flavor dynamical domain-wall lattice QCD near physical mass

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Analyses on possible systematics in some isovector nucleon observables in the RBC+UKQCD 2+1-flavor dynamical domain-wall fermion (DWF) lattice-QCD will be presented. The reports will be based mostly on the RBC+UKQCD Iwasaki+DSDR ensemble at pion mass of 170 MeV. The vector charge, axial charge, quark momentum and helicity fractions, and transversity are discussed. No autocorrelation issue is observed in the vector charge and quark momentum and helicity fractions. Blocked Jack-knife analyses expose significant growth of estimated error for the axial charge with increasing block sizes that are similar to or larger than the known autocorrelation time of the gauge-field topological charge. Similar growth is seen in the transversity. These two observables, however, do not seem correlated with the topological charge. Related preliminary results obtained jointly by the RBC and LHP collaborations using a RBC+UKQCD Iwasaki ensemble at physical pion mass may also be discussed if relevant.

Physics beyond the standard model / 276

SU(2) gauge theory with many flavors of domain-wall fermions

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We numerically study the SU(2) gauge theory with many flavors. Dynamical simulation is performed with the standard domain-wall fermions in fundamental representation at numbers of flavors Nf=2,4,6, and 8. Nf dependence of the static potential, meson spectrum, and the eigenvalue spectrum of the Dirac operator is investigated so as to determine the phase structure.

Theoretical Developments / 277

Blocking versus Sampling

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The idea of blocking in configuration space has played an important role in the development of the RG ideas. However, despite
being half a century old and having had a huge intellectual impact, generic numerical methods to perform blocking for lattice models have progressed more slowly than sampling methods. Blocking may be essential to deal with near conformal situations. Typically, blocking methods have smaller statistical errors but larger systematic errors than sampling methods. This situation is evolving with recent developments based on the Tensor RG (TRG) method. We report recent results for spin and gauge lattice models obtained with this new method regarding searches for fixed points, calculations of critical exponents and resolutions of sign problems. An interesting model for comparison is the 2-dimensional O(2) model with a chemical potential which has a sign problem with conventional Monte Carlo but allows sampling with the worm algorithm and blocking with various TRG formulations. We compare the efficiency and accuracy of these methods and discuss the possibility of combining them.

Physics beyond the standard model / 278

Approaching Conformality

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We discuss our results on the thermal phase transition in color $SU(3)$ QCD with a large number N_f of fundamental fermions using lattice gauge theory. We study the dependence of the critical temperature T_c of the transition and of the coupling at T_c on N_f. These results are used to investigate precursory effects of conformality associated with the emergence of a non-trivial fixed point at large N_f and to show how real quark gluon plasma is smoothly connected to a strongly coupled system at zero temperature.

Nonzero temperature and Density / 279

Lattice simulations of G2-QCD at finite density II

Dr. WELLEGEHAUSEN, Bjoern [1]; Prof. VON SMEKAL, Lorenz [2]; Dr. MAAS, Axel [3]; Prof. WIPF, Andreas [4]

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G2-QCD is a QCD-like theory with fermionic baryons and fundamental quarks.
Unlike QCD it does not suffer from a fermion sign problem at finite baryon density and therefore allows to investigate effects of fermionic baryons on the G2-QCD phase diagram with standard Monte-Carlo methods.
In the talk we present recent results on the phase diagram at zero and non-zero temperature with an emphasis on Chiral- and Diquark-Condensation.
We discuss various transitions in the quark number density related to the observed mass hierarchy in the spectrum and show evidence for a first order nuclear matter transition.

Standard model parameters and renormalization / 280

Towards a new determination of the QCD Lambda parameter from running couplings in the three-flavour theory

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We review our new strategy and current status towards a high precision computation of the Lambda parameter from three-flavour simulations in QCD. To reach this goal we combine specific advantages of the Schroedinger functional and gradient flow couplings.

Physics beyond the standard model / 281

Dark matter baryon candidates in the sextet gauge model

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The strongly coupled near-conformal gauge theory with two fermion flavors in the two index symmetric (sextet) representation of the SU(3) color gauge group is the minimal realization of the composite Higgs mechanism. We discuss the baryon mass spectrum in this theory using staggered fermion operators to identify dark matter candidates.

Hadron spectroscopy and interaction / 282

Investigation of the tetraquark candidate a_0(980): technical aspects.

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The structure of the light-scalar meson a_0(980) is under debate. It might be of quark-antiquark, diquark-antidiquark or mesonic molecule type. We have implemented corresponding interpolating field operators composed of two and of four quarks, as well as operators of two-meson type, to study the structure of a_0(980). The computation of the correlation matrix is rather challenging, because of e.g. closed fermion loops, quark propagation within a timeslice or disconnected pieces. To keep the statistical errors on an acceptable level, one needs to resort to different techniques for different entries and diagrams of the correlation matrix. Here we discuss these techniques in the context of first numerical results.

Weak Decays and Matrix Elements / 283

Improved currents for B to D(*) ell nu form factors from Oktay-Kronfeld heavy quarks

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The CKM matrix element |V_{cb}| can be extracted by combining experimentally determined branching fractions for B to D(*) ell nu decays with form factors from the lattice. While successful, the precision of this approach has been limited by heavy-quark discretization effects. An improved version of the Fermilab action, the Oktay-Kronfeld action, can be used to reduce heavy-quark discretization effects in calculations performed at the physical bottom and charm quark masses. Treating charm and bottom quarks as massive, we carry out tree-level improvement of the flavor-changing currents through third order in the momentum expansion.

Standard model parameters and renormalization / 284

Non perturbative renormalization and running of Delta F=2 four-fermion operators in the SF scheme.

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We present preliminary results of a non-perturbative study of the scale-dependent renormalization constants of a complete basis of Delta F=2 parity-odd four-fermion operators that enter the computation of hadronic B-parameters within the SM and beyond.
We consider non-perturbatively O(a) improved Wilson fermions and our gauge configurations contain two flavors of massless sea quarks.
The mixing pattern of these operators is the same as for a regularization that preserves chiral symmetry, in particular there is a "physical" mixing between some of the operators.
The renormalization group running matrix is computed in the continuum limit for a family of Schrödinger Functional (SF) schemes through finite volume recursive techniques. We compute non-perturbatively the relation between the renormalization group invariant operators and their counterparts renormalized in the SF at a low energy scale and we
provide non-perturbative estimates for the matching matrix between the lattice regularized theory and the various SF schemes.

Physics beyond the standard model / 285

Analysis of the scalar and vector channels in many flavor QCD

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In the search for a composite Higgs boson in walking technicolor models, many flavor QCD is an attractive candidate. Particularly promising is the Nf=8 theory, which has been found to have a composite flavor-singlet scalar as light as the pion. Based on simulations of this theory with the HISQ action at various fermion masses in the LatKMI collaboration, we will present our preliminary results on the scalar decay constant using the fermionic bilinear operator. We will then discuss a possible relation between the scalar decay constant and the decay constant of the techni-dilaton, which would be identified with a composite Higgs boson. The (axial) vector current is used to compute the S-parameter and the vector meson decay constant. Chiral behavior of these low-energy quantities will be also discussed.

Standard model parameters and renormalization / 286

Physical and cut-off effects of heavy charm-like sea quarks

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We simulate a theory with two dynamical O(a) improved Wilson quarks
whose mass M is close the charm quark mass and
at three values of the lattice spacing ranging from 0.066 to 0.038 fm.
This theory is a prototype to study the decoupling of heavy quarks.
We measure the mass and cut-off dependence of ratios of gluonic
observables defined from the Wilson flow or the static potential.
The size of the 1/M corrections can be determined and disentangled
from the lattice artifacts.
The difference with the pure gauge theory
is in the percent range when two quarks with a mass of the
charm quark are present.

Nonzero temperature and Density / 287

On curing the divergences in the quark number susceptibility

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Quark number susceptibility on the lattice, obtained by merely adding a \mu N-term with \mu as the chemical potential and N as the conserved quark number, has a quadratic divergence in the cut-off a. We show that it is simply a faithful representation of the corresponding continuum result. While one can eliminate it in the free theory by suitably modifying the action, as is popularly done, it can simply be subtracted off as well. Computations of higher
order susceptibilities, needed for estimating the location of the QCD critical point, then need a lot fewer number of quark propagators are at any order. We show that in the interacting theory this method of divergence removal works.

Theoretical Developments / 288

Energy-momentum tensor on the lattice and Wilson flow

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The energy-momentum tensor in lattice gauge theories requires renormalization because of the breaking of Poincare' group. The Wilson flow can be used in principle to set up non-perturbative, well-defined and, possibly, practically convenient strategies to define
a properly renormalized energy momentum tensor. I will present some preliminary data in this direction.

Physics beyond the standard model / 289

Walking technicolor: testing infra-red conformality with exact results in two dimensions

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We study two exactly solvable conformal models, the critical 2d Ising model and the
Sommerfield model on the lattice. We find that some conditions on the geometry of the
lattice must be fulfilled in order to obtain results free of systematic errors. In the Sommerfield model we also
introduce a mass deformation and measure the mass anomalous dimension, γ_m. We find that the explicit scale breaking of the lattice induces
corrections which have to be taken into account in order to reproduce γ_m
at the infrared fixed point. These results can be used to improve the methodology in the search for the conformal window in QCD-like theories with
many flavors.

Nonzero temperature and Density / 290

Lattice simulations of G2-QCD at finite density I

Dr. WELLEGEHAUSEN, Bjoern [1]; Prof. WIPF, Andreas [2]; Prof. VON SMEKAL, Lorenz [3]; Dr. MAAS, Axel [4]

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In G2-QCD the SU(3) gauge group of QCD is replaced by the exceptional Lie group G2. This replacement leads to a theory that does not have a sign problem and can be simulated at finite baryon density using standard lattice techniques. The price to pay is that it contains bosonic as well as fermionic baryons. The physics of the light bosonic baryons is expected to be analogous to other QCD-like theories without sign problem such as two-color QCD or QCD with adjoint quarks. As adjoint QCD, it also contains fermionic baryons such as nucleons and deltas to form G2-nuclear matter while it is known from quenched simulations that it resembles QCD more closely than adjoint QCD does. We review the properties of G2-QCD, our results on its baryon spectrum, and how the observed mass hierarchy in this spectrum is reflected in the baryon density at finite chemical potential.

Hadron spectroscopy and interaction / 291

A study of scattering in open charm channels

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Preliminary results from a study of DK and $D\pi$ scattering are presented using a set of anisotropic $N_f=2+1$ dynamical gauge field configurations generated by the Hadron Spectrum Collaboration. The variational method with a large operator basis is used in two lattice volumes to determine the excitation spectra of open charm mesons with the relevant scattering states containing one valence charm quark. Scattering observables and resonance parameters for open charm states are also discussed.

Physics beyond the standard model / 292

Gauge-invariant signature of spontaneous gauge symmetry breaking by the Hosotani mechanism

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We study the Hosotani mechanism on the lattice and show with the use of gauge invariant observables that SU(3) can break either to SU(2)xU(1) or U(1)xU(1). The novelty in this study is the strict gauge invariance of the observables used.
We take advantage of the inability of a U(1) flux to decay in the continuum limit. One interesting consequence is that the SU(2) and U(1) subgroups rotate locally in representations space but the introduced flux always follows the U(1) subgroup. We also investigate the stability of U(1) monopoles when the gauge symmetry is broken.

Hadron spectroscopy and interaction / 293

Gradient Flow Analysis on MILC HISQ Ensembles

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We present a final analysis of gradient flow and the associated scale w_0 measured on the $N_f=2+1+1$ HISQ ensembles. Compared to previously reported results, we have improved the interpolation to physical quark masses using chiral perturbation theory, adjusted for variations in charm quark mass between ensembles, and derived a `prediction' function for estimating the scale using w_0/a on new ensembles with unphysical quark masses. Additional results include a comparison of t_0/a to w_0/a and a test of agreement between the RHMC and RHMD generation algorithms.

Nonzero temperature and Density / 294

Towards exact worldline models of lattice gauge theory at finite density

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We integrate out all the link variables in the partition function of SU(N) or U(N) lattice gauge theory with the Wilson plaquette action, for arbitrary values of the lattice coupling. The partition function is recast as a Gaussian integral over auxiliary fields, after using suitable Hubbard-Stratonovich transformations. We extend our formalism to lattice gauge theories with staggered fermions at finite temperature and density, and show how to construct the corresponding monomer-dimer-polymer models for arbitrary values of the lattice coupling.

Standard model parameters and renormalization / 295

Isospin Effects by Mass Reweighting

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Most of today's lattice simulations are performed in the isospin symmetric limit in the light quark sector. A technique with moderate numerical cost to include effects of isospin breaking in the sea quark sector is mass reweighting. We will give a summary of the recent results on fine lattices with light quark masses.

In general reweighting corrects the weight of an ensemble which is sampled by a specific algorithm. In the case of mass corrections the reweighting factor is a ratio of the fermion determinants. The evaluation of this factor for which we use stochastic methods and the factor itself introduce fluctuations which increase the statistical uncertainties. We will show the quark mass and volume dependence of these fluctuations in the case of isospin breaking. Towards the physical light quark masses the effect of the correction increases and can have a significant impact for precision measurements in the light quark sector.

Nonzero temperature and Density / 296

The curvature of the QCD critical line from analytic continuation

Mr. NEGRO, Francesco [1]; Dr. SANFILIPPO, Francesco [2]; Mr. BONATI, Claudio [1]; D'ELIA, Massimo [3]; Mr. MARITI, Marco [3]; MESITI, Michele [3]

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We present preliminary results regarding the curvature of the critical line of N_f = 2+1 QCD with physical quark masses. We make use of the stout improved staggered fermions formulation, with a tree level improved Symanzik gauge action.

Nonzero temperature and Density / 297

Magnetic properties of the QCD medium

Dr. BONATI, Claudio [1]; Prof. D'ELIA, Massimo [2]; Mr. MARITI, Marco [3]; MESITI, Michele [1]; Mr. NEGRO, Francesco [1]; Dr. SANFILIPPO, Francesco [4]

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We present improved results regarding our determination of the magnetic susceptibility in QCD. We discuss also preliminary data on higher order terms contributions in B to the free energy and to the relative increase in the pressure.

Hadron Structure / 298

The leading disconnected contribution to the anomalous magnetic moment of the muon

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The hadronic vacuum polarization can be determined from the vector correlator in a mixed time-momentum representation. We explicitly calculate the disconnected contribution to the vector correlator, both in the $N_f = 2$ theory and with an additional quenched strange quark, using non-perturbatively $O(a)$-improved Wilson fermions. All-to-all propagators are computed using stochastic sources and a generalized hopping parameter expansion. Combining the result with the dominant connected contribution, we are able to estimate an upper bound for the systematic error that arises from neglecting the disconnected contribution in the determination of $(g-2)_\mu$.

Physics beyond the standard model / 299

Targeting the Conformal Window: Measuring the 0++ Scalar

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The light Higgs boson of the Standard Model could arise as the consequence of the weakly broken conformal symmetry in a strongly interacting gauge theory just below the conformal window. Here we present a novel idea to study the transition from conformal to confining behavior using an SU(3) gauge theory with four light and eight heavy flavors. This system interpolates between the 12 flavor conformal and the 4 flavor chirally broken theory as the mass of the heavy flavors are varied. We show first results on the determination of the isosinglet 0++ state as it interpolates between QCD-like and conformal behavior.

Hadron Structure / 300

Suppression of excited-state effects in lattice determination of nucleon electromagnetic form factors

Dr. VON HIPPEL, Georg [1]; Dr. CAPITANI, Stefano [1]; Dr. DJUKANOVIC, Dalibor [1]; Dr. GREEN, Jeremy [1]; Mr. HUA, Jiayu [1]; Dr. JAEGER, Benjamin [2]; Dr. JUNNARKAR, Parikshit [1]; Prof. MEYER, Harvey [1]; Dr. RAE, Thomas [1]; Prof. WITTIG, Hartmut [1]

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We study the ability of a variety of fitting techniques to extract the ground state matrix elements of the vector current from ratios of nucleon three- and two-point functions that contain contaminations from excited states. Extending our high-statistics study of nucleon form factors, we are able to demonstrate that the treatment of excited state contributions in conjunction with approaching the physical pion mass has a significant impact on the Q^2 dependence of the form factors.

Poster session - Board 6 / 301

Tuning of the strange quark mass with optimal reweighting

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Quark mass reweighting can be used to tune the mass of dynamical quarks. The basic idea is to use gauge field ensembles generated at some bare mass parameters to evaluate observables at different bare sea quark masses. This involves the computation of so called reweighing factors which are given as ratios of fermion determinants. In the case of simulations including the strange quark, reweighting can be used to improve the approach towards physical quark masses. Optimal reweighting strategies combine a change of the strange quark mass with a change of the light quark masses in order to minimize the fluctuations of the reweighting factor. We present numerical test of such strategies for recent CLS2 simulations and a software package for mass reweighting based on openQCD.

Algorithms and Machines / 302

Achieving strong scaling in many-GPU calculations in lattice QCD

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We describe recent additions to the QUDA software library that are
aimed at extending strong scaling in multi-GPU lattice calculations.
These include the addition of CPU-thread support in order to increase
concurrency and improve the overlap of computation and communication
in Krylov solver routines, as well as the modifications needed to enable the GPUDirect RDMA feature recently introduced by NVIDIA and Mellanox. However, we focus in particular on the implementation and performance of so-called S-step variants of common Krylov solvers on current NVIDIA hardware. The S-step formulations are designed to reduce the number of global synchronizations associated
with the calculation of vector inner products. These formulations may, when combined with communication-reducing methods such as additive Schwarz preconditioning, form the basis for a set of optimal Krylov solvers for many-GPU calculations.

Hadron spectroscopy and interaction / 304

Radial and orbital excitation energies of charmonium

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The system of charmonium has several excited states below the energy threshold for decay into D and Dbar mesons, which can in principle be studied accurately in lattice QCD. Studies that include many states in the spectrum have typically only been done at one value of the lattice spacing and with light quarks in the sea. Here we give results for radial and orbital excitation energies for charmonium from a calculation on 2+1+1 MILC configurations at multiple lattice spacings and including physical values for u/d quark masses. We use the HISQ formulation for c for small discretisation errors and smeared operators to improve excited state overlap.

Hadron spectroscopy and interaction / 305

Search for a bound H-dibaryon using local six-quark interpolating operators

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Early results will be presented from a Lattice QCD study seeking a
bound H-dibaryon using Nf=2 flavors of O(a) improved Wilson fermions and a quenched strange quark. We solve the generalized eigenvalue problem constructed using a variational basis of interpolators consisting of the two independent local products of six positive-parity-projected quarks with the appropriate quantum numbers, which belong to the singlet and 27-plet irreducible representations of flavor SU(3). To expand this basis, we also independently vary the quark-field smearing. We employ a "blocking" algorithm for the contractions and all-mode-averaging in order to achieve high performance and large statistics. Results will be presented for at least two different pion masses.

Nonzero temperature and Density / 306

Chiral restoration and deconfinement in two-color QCD with two flavors of staggered quarks

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We study chiral restoration and deconfinement in two-color QCD with two flavors of staggered quarks using a RHMC algorithm on GPUs. We measure the chiral condensate and the corresponding chiral susceptibility over the lattice coupling across the finite temperature transition. Using Ferrenberg-Swendsen reweighting we extract the maxima of the chiral susceptibility in order to determine pseudo-critical couplings on various lattices suitable for chiral extrapolations. These are then used to fix the relation between coupling and temperature in the chiral limit, and to extract the critical exponents for magnetic scaling.

Hadron Structure / 307

Study of the couplings of QED and QCD from the Adler function

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The QCD contributions to the vacuum polarisation function are responsible for a large fraction of the theoretical uncertainty in the running of the QED coupling and therefore limit its impact on electroweak precision tests. We use lattice simulations with N_f=2 O(a) improved Wilson fermions to determine the Adler function in a broad range of momentum transfer Q^2. The running of the QED coupling, including valence contributions from u, d, s and c quarks, is compared to phenomenological results at intermediate Q^2 values. In the large Q^2 regime, the lattice determination of the Adler function is fitted to perturbation theory in order to explore the feasibility of a determination of the strong coupling constant.

Hadron Structure / 308

Electromagnetic structure of charmed baryons in Lattice QCD

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The electromagnetic form factors of \Sigma_c, \Xi_cc, \Omega_c and \Omega_cc baryons are computed and their electric and magnetic charge radii as well as their magnetic moments are extracted in 2+1 flavor Lattice QCD. Extrapolated physical point results show that the charge radii and magnetic moments are smaller compared to those of, e.g., proton. Investigating the individual quark contributions suggests that the existence of the heavy charm quark is responsible of such decrease.

Nonzero temperature and Density / 309

Temperature dependence of bottomonium spectral functions

Mr. HARRIS, Tim [1]; Dr. RYAN, Sinead [2]; KIM, Seyong [3]; AARTS, Gert [4]; SKULLERUD, Jon-Ivar [5]; ALLTON, Chris [4]; LOMBARDO, Maria Paola [6]

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I will present updated results from the FASTSUM collaboration on the bottomonium spectrum at finite temperature from lattice NRQCD on anisotropic $N_f=2+1$ Wilson clover ensembles.
Further systematic checks on the reconstruction of the spectral function at high temperatures where few correlator data are available will be discussed.
This is relevant to understand the reliability of the observed temperature dependence and the extraction of information on the ground state widths.
Preliminary results on higher orbital excitations will be shown.

Hadron Structure / 310

Towards the physical point hadronic vacuum polarisation from Möbius DWF

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We present steps towards the computation of the leading-order hadronic contribution to the muon anomalous magnetic moment on RBC/UKQCD physical point DWF ensembles. We discuss several methods for controlling and reducing uncertainties associated to the determination of the HVP form factor.

Vacuum Structure and Confinement / 311

Surface operators study within the lattice QCD

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The most important probes for the phase states of a four-dimensional gauge field theory are the Wilson and t'Hooft line operatros that are defined on one-dimensional curves in the space-time. However, for more detail understanding of four-dimensional gauge field theory dynamics and vacuum topology we need additional probes expressed by operators defined on the subspaces with higher dimensions. Possible candidates are operators that are defined on the two-dimensional surface in the four-dimensional space-time. In the present work the surface operator in the lattice QCD is studied. The Witten parameter dependence on the surface area and volume studied in confinement and deconfinement phases.

Nonzero temperature and Density / 312

Chiral dynamics in the low-temperature phase of QCD

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We investigate the low-temperature phase of QCD and the crossover region with two light flavors of quarks. The chiral expansion around the point $(T, m_q = 0)$ in the temperature vs. quark-mass plane indicates that a sharp real-time excitation exists with the quantum numbers of the pion. We determine its dispersion relation and test the applicability of the chiral expansion. The time-dependent correlators are also analyzed using the Maximum Entropy Method (MEM), yielding consistent results. Finally, we test the predictions of ordinary chiral perturbation theory around the point $(T = 0, m_q = 0)$ for the temperature dependence of static observables. Around the crossover temperature, we find that all quantities considered depend only mildly on the quark mass in the considered range 8MeV $\leq \overline{m}^{\overline{\text{MS}}} \leq$ 15MeV.

Hadron Structure / 313

Nucleon and pion structure in n_f=2 QCD

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We determine singlet and non-singlet hadron structure matrix elements for the nucleon and the pion from n_f=2 simulations at the physical quark mass.

Hadron Structure / 314

Decay constants of the pion and its excitations on the lattice

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We present a lattice QCD calculation of the ratios of decay constants of the excited states of the pion, to that of the pion ground state. We use an anisotropic clover fermion action with three flavors of quarks, and study the pion decay constants at three values of the light-quark masses, corresponding to pion masses of 391, 524 and 702 MeV. We find that the decay constant of the first excitation, and more notably of the second, is suppressed with respect to that of the ground-state pion, but that the suppression shows little dependence on the quark mass. The strong suppression of the decay constant of the second excited state is consistent with its interpretation as a predominantly hybrid state.

Hadron spectroscopy and interaction / 315

Flavored tetraquark spectroscopy

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The very recent confirmation of the Z(4430) charged resonance by the LHCb experiment strongly suggests the existence of QCD bound states with four quarks.
We report some preliminary results about hypothetical flavored tetraquark hadrons.
Such states are particularly amenable to Lattice QCD studies as their interpolating operators do not overlap with those of ordinary hidden-charm mesons.

Vacuum Structure and Confinement / 316

Anisotropy of the quark anti-quark potential in a magnetic field

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We determine the static quark anti-quark potential for QCD at the physical point in the presence of an external magnetic field.
The potential is anisotropic, in particular it is steeper in the directions orthogonal to the magnetic field than in the parallel one.
The string tension increases (decreases) in the orthogonal (parallel) directions; the absolute value of the Coulomb coupling and the Sommer parameter show an opposite behavior.

Hadron Structure / 317

Quark Spin in the Nucleon with Overlap Fermion

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The disconnected insertion part of the quark contributions to the nucleon spin are calculated with overlap fermion on DWF configurations. This work is done by calculating the disconnected three point correlation functions through the anomalous Ward identity. The quark loop of the pseudoscalar density is calculated with low-mode average and grid-noise estimate for the high modes. The overlap operator is used for the topological charge density.

Weak Decays and Matrix Elements / 318

Semileptonic form factors of pseudoscalar mesons from Nf=2+1+1 Twisted Mass lattice QCD

Mr. RIGGIO, Lorenzo [1]; Prof. LUBICZ, Vittorio [2]; Dr. SIMULA, Silvano [1]; Dr. CARRASCO, Nuria [1]; Dr. TARANTINO, Cecilia [3]; Mr. LAMI, Paolo [4]; Ms. PICCA, Eleonora [4]; Dr. DIMOPOULOS, Petros [5]; Dr. SANFILIPPO, Francesco [6]; Dr. FREZZOTTI, Roberto [7]

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We present a lattice QCD determination of the vector and scalar form factors of the kaon semileptonic decay K->pi nu l , and of the D meson semileptonic decays D->(K/pi) nu l which are relevant for the extraction of the CKM matrix element |Vus|, |Vcd| and |Vcs| from experimental data. Our preliminary results are based on the gauge configurations produced by the European Twisted Mass Collaboration with Nf=2+1+1 dynamical fermions, which account for the sea quark effects of the up, down, strange and charm quarks. We simulated at three different values of the lattice spacing and with pion masses as small as 210 MeV.

Physics beyond the standard model / 319

Loop formulation of supersymmetric Yang-Mills quantum mechanics

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The conjectured holographic duality between supersymmetric Yang-Mills quantum mechanics and type IIa string theory in principle allows to probe the physics of certain supergravity black holes by lattice Monte Carlo simulations. In this talk we derive the fermion loop formulation of the 4 and 16 supercharge SU(N) theory on the lattice. The loop formulation naturally separates the contributions to the partition function into its bosonic and fermionic parts and hence provides a way to control a potential fermion sign problem arising from the Pfaffian phase. We present first numerical results for the theories at large values of N and down to low temperatures.

Nonzero temperature and Density / 320

Charmonium spectral functions from 2+1 flavour lattice QCD

Mr. PASZTOR, Attila [1]; Dr. BORSANYI, Szabolcs [2]; Dr. HOELBLING, Christian [3]; Prof. SCHÄFER, Andreas [4]; Dr. DÜRR, Stephan [5]; Dr. NOGRADI, Daniel [6]; Dr. KRIEG, Stefan [7]; Mr. TROMBITAS, Norbert [8]; Mr. MAGES, Simon [4]; Prof. KATZ, Sandor [9]; Dr. SZABO, K. Kalman [5]; Dr. TOTH, Balint [3]; Prof. FODOR, Zoltan [10]

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Finite temperature charmonium spectral functions in the pseudoscalar and vector channels are studied in lattice QCD with 2+1 flavours of dynamical Wilson quarks, on fine isotropic lattices (with a lattice spacing of 0.057fm), with a pion mass of 545MeV. The highest temperature studied is approximately 1.4Tc. Up to this temperature no significant variation of the spectral function is seen in the pseudoscalar channel. The vector channel shows some temperature dependence, which seems to be consistent with a temperature dependent low frequency peak related to heavy quark transport, plus a temperature independent term at omega>0. These results are in accord with previous calculations using the quenched approximation.

Nonzero temperature and Density / 321

QCD Thermodynamics With Continuum Extrapolated Wilson Fermions

Dr. BORSANYI, Szabolcs [1]; Dr. KRIEG, Stefan [2]; Dr. NOGRADI, Daniel [3]; Mr. TROMBITAS, Norbert [4]; Dr. TOTH, Balint C. [5]; Prof. FODOR, Zoltan [6]; Dr. DURR, Stephan [7]; Dr. SZABO, Kalman K. [7]; Prof. KATZ, Sandor D. [8]; Dr. HOELBLING, Christian [5]

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We study 2+1 flavour QCD thermodynamics using Wilson fermions in the fixed scale approach. The temperature dependence of the renormalized chiral condensate, quark number susceptibility and Polyakov loop is determined at three pion masses down to 280~MeV. Four lattice spacings are used allowing for a controlled continuum limit.

Hadron spectroscopy and interaction / 322

Lattice QCD with 2+1 Flavors and Open Boundaries: First Results of the Baryon Spectrum

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Based on CLS simulations with 2+1 flavors and open boundaries we present first results of the baryon spectrum. We report on the status of our effort related to these simulations and the chiral extrapolation to the physical point.

Physics beyond the standard model / 324

Gauge and Higgs boson masses from an extra dimension

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We present novel calculations of the mass hierarchy of the $SU(2)$ pure gauge theory on a space-time lattice with an orbifolded fifth dimension. This theory has three parameters; the gauge coupling β, the anisotropy γ, which is a measure of the ratio of the lattice spacing in the four dimensions to that in the fifth dimension, and the extent of the extra dimension N_{5}. Using a large basis of scalar and vector operators we explore in detail the spectrum along the $\gamma = 1$ line, and for the first time we investigate the dependence of the spectrum on N_{5} and γ.

Nonzero temperature and Density / 325

Quark mass dependence of quarkonium properties at finite temperature

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Quarkonium properties at finite temperature are studied with various quark masses in the range between those for the charm and bottom quarks. Our simulations are performed in quenched QCD with the $O(a)$-improved Wilson quarks on large and fine isotropic lattices at temperatures between about 0.7T_c and 1.4T_c. At both vanishing and finite momenta we discuss temperature and quark mass dependence of quarkonium correlation functions and related physical quantities: the quark number susceptibility and the heavy quark diffusion constant.

Hadron Structure / 326

Axial and tensor charges of baryons using twisted mass fermions

Prof. ALEXANDROU, Constantia [1]; Dr. CONSTANTINOU, Martha [1]; Dr. JANSEN, Karl [2]; Mr. HADJIYIANNAKOU, Kyriacos [1]; Mr. KALLIDONIS, Christos [3]; Dr. KOUTSOU, Giannis [3]

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We present results on the axial charges of the nucleon, the hyperons and charmed baryons
using a number of twisted mass fermions ensembles. This includes an $N_f=2$ ensemble with the physical value of the pion mass for which we also show results on the tensor structure of the nucleon.

Hadron spectroscopy and interaction / 327

Baryon spectrum with Nf=2+1+1 twisted mass fermions

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We present results on the masses of the low lying baryons using gauge configurations with $N_f=2+1+1$ flavors of maximally twisted mass fermions. The strange and charm quark masses are tuned to their physical values. We use three values of the lattice spacing, determined from the nucleon mass. Both cut-off effects and volume effects are investigated. We demonstrate that isospin symmetry breaking effects on the baryon masses are small and vanish at the continuum limit. Chiral extrapolations of the masses of the 20 spin-1/2 and 20 spin-3/2 baryons are performed using SU(2) χPT. After extrapolating to the physical pion mass and taking the continuum limit we find good agreement with the experimentally known baryon masses. Predictions are provided for the masses of the doubly and triply charmed Ω baryons, that have not yet been measured experimentally.

Theoretical Developments / 328

Conformal Lattice Field Theory on Spherical Manifolds

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Lattice radial quantization is a nonperturbative method especially suited to numerically solve Euclidean conformal field theories.
Tests are made for the critical surface of the
phi 4th theory at the Wilson-Fisher critical point
in 3D on R x S2 and in 2D on the Riemann sphere.
Simplicial lattice using the Finite Element Methods (FEM) or Regge calculus discretization are need to obtain full conformal symmetry
in the continuum. Possible applications to 4D gauge theories
are discussed.

Theoretical Developments / 329

Matrix product states for gauge field theories

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We consider the matrix product state formalism for the simulation of Hamiltonian lattice gauge theories. To this end, we define matrix product states which are manifestly gauge invariant. As an application, we study 1+1 dimensional one flavor quantum electrodynamics, also known as the massive Schwinger model. We are able to determine very accurately the ground state properties and one-particle excitations in the continuum limit. But we also simulate for the first time the full quantum non-equilibrium dynamics induced by a quench in the form of a uniform background electric field (i.e. the Schwinger pair creation mechanism). Furthermore we study the effects of charge screening and confinement in the vacuum. Finally, we comment on extensions of our method to higher dimensions.

Poster session - Board 4 / 330

Kaon and D meson semileptonic form factors from lattice QCD

Dr. PRIMER, Thomas [1]

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We present calculations of the $K\to\pi,l\nu$ and $D\to\pi,l\nu$ semileptonic form factors at $q^2=0$.
These form factors are important for the determination of the CKM matrix elements $\lvert{V_{us}}\rvert$ and $\lvert{V_{cd}}\rvert$ respectively.
This work uses the HISQ action for both valence quarks and sea quarks on MILC $N_f=2+1+1$ configurations.
We employ twisted boundary conditions to calculate the form factors at zero momentum transfer directly.
The $K\to\pi$ results are an update to previously published results with new data at the physical quark mass.
The $D\to\pi$ results are preliminary, working at the physical light quark mass at three different lattice spacings down to 0.06 fm.

Standard model parameters and renormalization / 331

Non-perturbative improvement of the axial current in N_f=3 lattice QCD

Dr. HEITGER, Jochen [1]; Mr. WITTEMEIER, Christian [2]; Dr. BULAVA, John [3]; Dr. DELLA MORTE, Michele [4]

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We present the results of a non-perturbative determination of the improvement coefficient c_A of the axial vector current in three-flavour lattice QCD with O(a) improved Wilson quarks and tree-level Symanzik improved gauge action. Our computation involves an improvement condition which is imposed at a constant physical volume of about 1.2 fm and employs the PCAC relation in the Schrödinger functional scheme with two different pseudoscalar states.

Nonzero temperature and Density / 332

Effects of near-zero Dirac eigenmodes on axial U(1) symmetry at finite temperature

Mr. TOMIYA, Akio [1]; FUKAYA, Hidenori [1]; Dr. GUIDO, Cossu [2]; Prof. HASHIMOTO, Shoji [2]; Dr. NOAKI, Junichi [2]

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We investigate the issue of possible restoration of the axial U(1) symmetry at finite temperature, using lattice simulations with the Mobius domain-wall fermion. In this talk, we focus on the effects of near-zero Dirac eigenmodes, which play a crucial role for both SU(2)xSU(2) chiral symmetry restoration and the restoration/breaking of axial U(1) symmetry.
Performing simulations at two different volumes, two different quark masses, and reweighting to other masses and to overlap Dirac operators, we study its volume, mass, residual mass dependences.

Standard model parameters and renormalization / 333

Non-perturbative renormalization of the axial current in N_f=3 lattice QCD

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We report on a non-perturbative computation of the renormalization factor Z_A of the axial vector current in three-flavour O(a) improved lattice QCD with Wilson quarks and tree-level Symanzik improved gauge action. Our normalization condition is formulated at constant physics in the same Schrödinger functional setup as is being used for the determination of the improvement coefficient c_A. It exploits the full, massive axial Ward identity to reduce finite quark mass effects in the evaluation of Z_A and correlators with boundary wave functions to suppress excited state contributions in the pseudoscalar channel.

Weak Decays and Matrix Elements / 334

Rare kaon decays from lattice QCD

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The rare kaon decays, $K \to pi nu nu_bar$ and $K \to pi l^+ l^-$, serve as ideal probes for the observation of New Physics (NP) effects. To isolate the NP contributions successfully, one needs to control the errors for Standard Model prediction from both short- and long-distance contributions.

RBC-UKQCD collaborations have performed a successful exploratory study on the calculation of the long-distance contributions to KL-KS mass difference, and are now developing the necessary methods to calculate the long-distance contributions to rare kaon decay amplitudes. In this talk, I will introduce the physical background for rare kaon decays and describe the state of our preliminary calculations.

Nonzero temperature and Density / 335

The in-medium heavy quark potential from quenched and dynamical lattice QCD

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We present the latest results from two projects focused on determining the temperature dependence of the heavy quark potential from lattice QCD. The real and imaginary part of this real-time potential is obtained from the position and width of the lowest lying peak in the Coulomb gauge Wilson line correlator spectral function [1]. Spectral information is extracted from Euclidean time data using a novel Bayesian approach different from the Maximum Entropy Method, which has been shown to be capable of reproducing the relevant spectral features in mock data tests [2].

Since the determination of the imaginary part is related to the extraction of a spectral width, a large N_\tau is required for a reliable result. Hence the first project deploys anisotropic quenched lattices 32^3xN_\tau (b=7.0 x=3.5) with N_\tau=24,32,40,48,56,64,72,80,96, corresponding to 838.8MeV \geq T\geq 209.7MeV [3]. We find that fits to the Debye mass are in good agreement with prediction from HTL perturbation theory even at rather low temperatures T\gtrsim T_C.

The second project provides for the first time a Bayesian spectral function based determination of the heavy quark potential in dynamical lattice QCD [4]. We use the isotropic Nf=2+1 48^3x12 ASQTAD lattices of the HotQCD collaboration [5] and find a clean transition from a confining to a Debye screened Re[V], while the small Nt precludes us from making a quantitative statement about Im[V]. Close agreement between the real part of the potential and the color singlet free energies at high temperatures or small distances is observed.

[1] A.R., T. Hatsuda, S. Sasaki Phys.Rev.Lett. 108 (2012) 162001
[2] Y.Burnier, A.R. Phys.Rev.Lett. 111 (2013) 18, 182003
[3] Y. Burnier, A.R. in preparation
[4] O. Kaczmarek, A.R. in preparation
[5] A.Bazavov et al. PRD85(2010)074501

Poster session - Board 35 / 336

NRQCD based S- and P-wave Bottomonium spectra at finite temperature from 48^3x12 lattices with Nf=2+1 light HISQ flavors

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We present the results of a recent study on the in-medium modification of the spectral properties of Bottomonium S-wave (\Upsilon) and P-wave (\chi_b) states. The medium degrees of freedom are represented by 48^3x12 HotQCD lattices with Nf=2+1 light HISQ flavors, which span the temperature range 140.40(MeV)(= 0.911T_C) < T < 248.63(MeV)(= 1.614T_C). The heavy quarks on the other hand are treated as probes, traveling in the background of the medium fields according to non-relativistic QCD (NRQCD) .

Spectral functions are extracted from the NRQCD propagators using a novel Bayesian approach, which is contrasted to the standard Maximum Entropy method. We confirm the finding of previous studies that \Upsilon retains a well defined peak structure even at 1.6TC. Inspection of its mass reveal that medium effects only begin to play a role above T\sim175MeV, while its width appears to grow monotonously. For \chi_b we find that with the new Bayesian method we are able to resolve a ground state peak also up to T=248.6MeV, contrary to the MEM, which suggests ground state melting already at T>205MeV.

Weak Decays and Matrix Elements / 337

Charm physics with physical light and strange quarks using domain wall fermions

Dr. JUETTNER, Andreas [1]

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This talk will provide an overview of RBC/UKQCD's charm project on their 2+1 flavour physical point ensembles using Moebius Domain Wall Fermions for the light as well as for the charm quark. After a brief motivation of DWF as a suitable heavy quark discretisation we will show first results for masses and matrix elements.

Theoretical Developments / 338

Locally smeared operator product expansions

Dr. MONAHAN, Christopher [1]; Prof. ORGINOS, Kostas [2]

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We propose a new ``smeared'' operator product expansion (sOPE) in
which the set of local operators in the OPE are replaced by their locally smeared counterparts, generated by the gradient flow. The flow time, or smearing, parameter serves as a regulator for both Wilson coefficients and operator products. Matrix elements determined
nonperturbatively on the lattice using smeared degrees of freedom remain finite in the continuum limit, provided the physical smearing scale is kept fixed. We study the sOPE in scalar field theory and discuss the application to Deep Inelastic Scattering.

Physics beyond the standard model / 339

Beyond the Standard Model Matrix Elements with the gradient flow

Dr. SHINDLER, Andrea [1]; Dr. DE VRIES, Jordy [1]; Prof. LUU, Tom [1]

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With the gradient flow, we propose to calculate the QCD component of key
beyond the Standard Model (BSM) matrix elements related to quark and strong theta-CP violations
and the strange scalar content within the nucleon.
The former set of matrix elements impacts our understanding of Electric
Dipole Moments (EDMs) of nucleons and nuclei (a key signature of BSM physics),
while the latter contributes to elastic recoil of Dark Matter particles of nucleons and nuclei.
If successful, these results will lay the foundation for extraction of
BSM observables from future low-energy, high-intensity and high-accuracy experimental measurements.

Algorithms and Machines / 340

Conjugate Directions in Landau and Coulomb Lattice Gauge Fixing

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We provide details of our implementation of a non-linear conjugate gradient method for Landau and Coulomb gauge fixing with Fourier acceleration. We find clear improvement over the Fourier accelerated steepest descent method, with the average time taken for our algorithm to converge to a fixed, high accuracy, being lower by a factor of 2 to 4 for several lattice volumes.

Theoretical Developments / 341

Testing volume independence of large N gauge theories on the lattice

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We present the results of our direct precision test of volume independence for SU(N) Yang-Mills theory on the lattice with Wilson action. Wilson loop expectation values at large N are obtained by extrapolation and its finite volume dependence examined for different boundary conditions.

Hadron spectroscopy and interaction / 342

Simulating two dimensional two-color QCD using purely bosonic variables

Mr. AUGUST, Daniel [1]; Dr. WELLEGEHAUSEN, Bjoern [2]; Prof. WIPF, Andreas [3]

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The numerical calculation of the fermion determinant is one of the most costly computational tasks in lattice QCD.
For massless two-color QCD in two dimensions we are able to calculate the fermion determinant analytically, allowing us to obtain high precision results for the mass spectrum of the theory.
In the talk we review our lattice formulation in terms of purely bosonic variables and present first results on the mass spectrum.

Poster session - Board 22 / 343

Renormalization of parton distribution functions and their moments

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Lattice QCD calculations of parton distribution functions have so far been restricted to only their first few Melin moments. Broken rotational symmetry on the lattice introduces unavoidable power divergent mixing of lattice twist-2 matrix elements of different spin that obscures the continuum limit. Here I discuss new options that either avoid power divergent mixing or allow us to perform the subtractions that are needed in order to obtain higher moments.

Standard model parameters and renormalization / 344

NPR step-scaling across the charm threshold

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While Non-Perturbative Renormalisation by itself can be done at any scale, converting it to a perturbative scheme introduces a systematic error decreasing with the scale. In the case of the B_K four quark operator, this is now the dominant error on the MSbar result at 3 GeV. Increasing this scale requires both the access to finer lattices and a correct treatment of the charm effects. We will present a strategy based on step-scaling with a new set of Nf=2+1+1 ensembles generated by the RBC/UKQCD collaboration. In those preliminary results, we will use two different RI/SMOM schemes to estimate the matching error, and we will show that our data gives us good control on chiral and continuum limits.

Hadron Structure / 345

Leading-order hadronic contribution to $g_\mu-2$ from $N_f=2+1$ simulations down to the physical pion mass

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For the Budapest-Marseille-Wuppertal collaboration.

We present preliminary lattice QCD results for the leading-order hadronic contribution to the muon anomalous magnetic moment. Computations are based on 2+1 flavour simulations with HEX-smeared clover fermions and pion masses down to its physical value. Besides the traditional approach, several methods implementing derivatives of the hadronic vacuum polarization are investigated and compared.

Vacuum Structure and Confinement / 346

Exploring confinement in SU(N) gauge theories with double-trace Polyakov loop deformations

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Recent results applying resurgence theory to finite-temperature field theories yield a detailed analytic structure determined by topological excitations. We examine finite-temperature SU(N) lattice gauge theories in light of these results. Double-trace Polyakov loop deformations move through different regions of the confined phase characterized by continuous change in the adjoint Polyakov loop. Lattice models show how the behavior of monopole constituents of calorons can change in the different confining regions. We conjecture that the pure SU(N) gauge theory is close to a special symmetric point where monopole effects give rise to Casimir string-tension scaling.

Physics beyond the standard model / 347

Four-fermi anomalous dimension with adjoint fermions

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The four-fermi interaction can play an important role in models of strong dynamical EW symmetry breaking if the anomalous dimension of the four-fermi operators becomes large in the IR.
The anomalous dimension can be computed nonperturbatively using a Schroedinger functional formalism. We present a computation of the four-fermi anomalous dimension for the SU(2) gauge theory with two flavors of Dirac fermions in the adjoint representation.

Hadron Structure / 348

Nonperturbative renormalisation for low moments of light-meson distribution amplitudes

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We discuss nonperturbative renormalisation of the leading-twist flavour non-singlet operators needed for the calculation of the first and second moments of light-meson distribution amplitudes. On the lattice we use a regularisation-independent symmetric (or non-exceptional) momentum scheme, RI/SMOM, which, for the second moment, allows us to include mixing with a total-derivative operator. We calculate the conversion functions needed to connect the RI/SMOM results to MSbar.

Hadron Structure / 349

A Study of the anomalous magnetic moment of the muon computed from the Adler function

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We compute the Adler function from vacuum polarization data with twisted boundary conditions using numerical derivatives. The study is based on CLS ensembles with two flavours of O(a) improved Wilson fermions. To describe the momentum dependence and to extrapolate the lattice data to the continuum limit and to the physical point, we perform a combined fit and compare our results for the Adler function to phenomenology. In addition, the Adler function provides an alternative method to compute the anomalous magnetic moment of the muon. We compare our results from this approach to a determination using a more standard method.

Theoretical Developments / 350

Tensor renormalization group study of the 2d O(3) model

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We study the two-dimensional O(3) model on the lattice using the Tensor Renormalization Group (TRG) approach, with the goal of understanding asymptotic scaling at both the large volume, and large beta limit. Harmonic analysis on the Boltzmann weight introduces a sign problem into the partition function, which makes the model difficult to study with the Worm Algorithm. The TRG is insensitive to the sign problem because it relies on projections onto eigenstates of positive matrices. Thermodynamic quantities are calculated for finite volumes, as well as the infinite volume limit, and compare well with Monte Carlo results. Prospects of parallelizing the TRG method to enable large scale calculations, which would aid in the computation of correlation functions, are briefly discussed, along with our progress on implementing these algorithms on the Blue Gene/Q.

Poster session - Board 18 / 351

Fast evaluation of multi-hadron correlation functions

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In recent work, it has been shown that contractions for multi-nucleon systems can be cast in terms of weighted sums of determinants of matrices constructed from quark propagators. For typical correlation functions even for few nucleon systems, the number of such determinants can be very large depending on the complexity of the interpolating fields that are used. We investigate efficient methods for determinant calculations making use of rank-one (and higher-rank) substitutions. Results will be presented that show that these methods provide very significant speedups in calculations of contractions for multi-hadron systems over calculations based on LAPACK routines.

Nonzero temperature and Density / 352

Temperature dependence of meson screening masses; a comparison of effective model with lattice QCD

Mr. ISHII, Masahiro [1]; Dr. SASAKI, Takahiro [2]; Dr. KASHIWA, Kouji [3]; Prof. KOUNO, Hiroaki [4]; Prof. YAHIRO, Masanobu [1]

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We analyze the pion screening mass calculated with lattice QCD, using the entanglement-PNJL (EPNJL) model. The EPNJL model well reproduces the lattice QCD result. We then predict the sigma meson screening mass with the model. The chiral symmetry restoration can be exhibited by the difference between the pi and sigma meson screening masses. After the chiral symmetry restoration, the two screening masses rapidly approach the free-field limit from below. Furthermore, we consider the effective restoration of the axial symmetry from lattice QCD results on a0 and pi meson screening masses. Finally, we investigate the order of the two- flavor chiral phase transition in the chiral limit.

Poster session - Board 20 / 353

Exploring the phase diagram of Euclidean dynamical triangulations

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I present the results of a study of Euclidean dynamical triangulations (EDT) in an attempt to formulate a theory of quantum gravity and to make contact with Weinberg's asymptotic safety scenario. There are two unphysical phases appearing in EDT, neither of which resembles semiclassical gravity. When the phase diagram is enlarged by including a nontrivial measure term a new region of the phase diagram dubbed the "crinkled" region appears. It is shown that this region does not behave like semiclassical gravity, despite initial optimism. Attempts to reconcile this behavior with the results found in functional renormalization group studies that support asymptotic safety are discussed.

Hadron spectroscopy and interaction / 354

Free-form Smeared Bottomonium Correlation Functions

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Gauge-invariant sources with a hydrogen wave function shape are constructed for bottomonium two-point correlation functions using the free-form smearing technique. The bottomonium spectrum is extracted from free-form smeared correlation functions. Results are compared with conventional smearing techniques.

Theoretical Developments / 355

TEK twisted gradient flow running coupling

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We measure the running of the twisted gradient flow coupling in the Twisted Eguchi-Kawai (TEK) model, the SU(N) gauge theory on a single site lattice with twisted boundary conditions in the large N limit.

Hadron spectroscopy and interaction / 356

An investigation of meson spectroscopy on isotropic clover lattices at the SU(3) flavor-symmetric point

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We present an investigation of the excited meson spectrum at the N_f= 3 point obtained on isotropic clover lattices with a plaquette Wilson gauge action, and a NP-improved clover fermion action, at a lattice spacing of a \simeq 0.08 fm, and compare with corresponding calculations on an anisotropic lattice at fine temporal lattice spacing but a spatial lattice spacing of a_s \simeq 0.125 fm. The methodology adopted follows that employed in the calculation of the spectrum on anisotropic lattices, and we test the efficacy of that approach for isotropic lattices. In particular, we explore the extent to which rotational symmetry for predominantly single-hadron states is realized. By comparison of the energy levels with that obtained using the anisotropic lattice, we obtain an indication of discretization uncertainties in the single-hadron spectrum.

Nonzero temperature and Density / 357

Exploring the QCD phase diagram with conserved charge fluctutaions

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Higher order cumulants of fluctuations of conserved charges are an important diagnostic tool for the thermodynamic properties of strong interacting matter close to freeze out at LHC energies as well as in the entire energy range covered with the beam energy scan (BES) at RHIC.
We present recent progress on the calculation of conserved charge fluctuations with highly improved staggered quarks (HISQ action).
In particular we will focus on higher order cumulants up to the 6th order
of net baryon number, net electric charge and net strangeness fluctuations. We will discuss how these quantities approach the hadron resonance gas at low temperatures and to what extent they show sensitivity to universal scaling behavior. Based on this analysis we discuss possible consequences for the QCD phase diagram and the
radius of convergence of the Taylor expansion of the QCD partition function. The latter can be used to locate the QCD critical point.
Furthermore, we specify a procedure to extract freeze-out conditions from various ratios of conserved charge fluctuations
measured in the BES at RHIC.

Weak Decays and Matrix Elements / 359

Kl - Ks mass difference computed with a 171 MeV pion mass

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In this work, I used a $32^3 \times 64 \times 32$, 2+1 flavor domain wall lattice with Iwasaki+DSDR gauge action. The pion mass is 171 MeV and the kaon mass is 492 MeV. We implement the Glashow-Iliopoulos-Maiani (GIM) cancellation using charm quark masses of 750 MeV and 592 MeV. This is an intermediate calculation, in that we are using both a coarse lattice spacing (1/a = 1.37GeV) so we expect significant discretization error coming from charm quark mass and we are also using unphysical kinematics for the pion. The main purpose of this calculation is to identify the contribution from the two pion intermediate state when the energy of a two pion state is smaller than that of the kaon.

Poster session - Board 42 / 360

The effective U(1)-Higgs theory at strong coupling on optical lattices?

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We study the U(1)-Higgs model in two dimensions in the strongly coupled regime. The goal is to generate an effective theory where link variables are integrated out, producing 4-field operators. This theory can be matched with the second-order perturbation theory effective Hamiltonian for the Bose-Hubbard model. Such correspondence can then be exploited for building a lattice gauge theory simulator on optical lattices.

Hadron Structure / 361

Strange quark momentum fraction from overlap fermion

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We present a calculation of $\langle x \rangle$ for the strange quark in the nucleon. We adopt overlap fermion action on 2 + 1 flavor domain-wall fermion configurations on the $24^3 \times 64$ lattice. Smeared grid Z_3 sources are deployed to calculate the nucleon two-point function with low-mode substitution. Even-odd grid sources and time-dilution technique with stochastic noises are used to calculate the high mode contribution to the quark loop. Low mode averaging is applied to reduce the statistical error of the disconnected insertion calculation.

Weak Decays and Matrix Elements / 362

Leptonic B and D decay constants with 2+1 flavor asqtad fermions

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We present the status of our updated D and B meson decay-constant analysis, based on the MILC Nf=2+1 asqtad gauge ensembles. Heavy quarks are incorporated using the Wilson clover action with the Fermilab interpretation. This analysis includes ensembles at five lattice spacings from a=0.045 to 0.15 fm, and light-quark sea masses down to 1/20 of the strange-quark mass. A complete chiral-continuum extrapolation based on partially quenched staggered chiral perturbation theory is presented, along with a detailed analysis of systematic errors.

Poster session - Board 41 / 363

$2+1$ flavor measurement for η and η' masses using domain wall fermion

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The $\eta-\eta'$ mass splitting coming from anomalous effect on U(1) axial currents has been a historical issue.
%
The QCD gauge field topology with instanton can explain this problem and show consistent result with experimental mass of η'.
%
Based on the $2+1$ flavor lattice QCD simulation, previous $\eta-\eta'$ masses study shows about 15\% level of accuracy.
%
With the advanced computational capability of GPU, we can process more bigger and finer lattice data for higher precision measurement.
%
In this work, we will show our preliminary $\eta-\eta'$ mass result calculated on $24^3\times 64$ and $32^3\times 64$ Iwasaki gauge lattices corresponding to $a^{-1} = 1.73$GeV.

Weak Decays and Matrix Elements / 364

B-physics with domain-wall light quarks and nonperturbatively tuned relativistic b-quarks

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We compute B-meson decay-constants and neutral B-meson mixing using relativistic b-quarks and domain-wall light quarks. We present results for fB, fBs, and their ratio including a complete systematic error budget from an analysis of five sea-quark ensembles with pion masses as light as ~290 MeV and two lattice spacings of a~0.11 and 0.08 fm. We are currently adding data at the physical pion mass using the M"oebius domain-wall ensemble with a~0.11 fm recently generated by the RBC and UKQCD collaboration in order to reduce the dominant systematic uncertainty from the chiral extrapolation. We also report on progress on our calculation of the B-mixing matrix elements.

Poster session - Board 40 / 365

Leveraging LLVM for Lattice QCD calculations

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The Low Level Virtual Machine (LLVM) compiler infrastructure is a promising platform for development of code that features performance portability across a wide variety of architectures. It's widely embraced by HPC industry and academia and high performance code generating backends are available and supported for many relevant architectures such as CUDA, X86-64, PowerPC64 including extensions for the A2Q processor.
The QDP-JIT/LLVM library leverages the source- and target-independent code representation known as the LLVM intermediate representation (IR) to generate LQCD kernels from a high level C++ API. Optimizer passes transform the IR in a suitable way for the target platform.
We present the QDP-JIT technology and performance numbers resulting from Chroma HMC for a variety of architectures including the new BG/Q support.

Standard model parameters and renormalization / 366

Renormalization of Flavor Singlet and Nonsinglet Fermion Bilinear Operators

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We compute the difference in the renormalization of flavor singlet and nonsinglet fermion bilinear operators, to 2 loops in perturbation theory. Our results are applicable to a rather wide class of lattice actions with Symanzik improved gluons, stout links and clover fermions, including the Twisted Mass and SLiNC actions.

Nonzero temperature and Density / 367

Phase diagram of QCD at finite isospin chemical potential with Wilson fermions

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We investigate the structure of the phase diagram of QCD at finite isospin chemical potential with Wilson fermions.
From the behavior of meson correlators in temporal and spatial directions, Polyakov loop, isospin density and susceptibilities as a function of isospin chemical potential at zero and finite temperature, we extract the QCD phases at finite isospin chemical potential and temperature.
We make comparison among our results, previous studies with effective theories, lattice QCD with KS fermions and high density QCD with heavy quark limit.

Poster session - Board 39 / 368

Targeting the Conformal Window: Determining the Running Coupling

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In order to study the transition from conformal to confining behavior of an SU(3) gauge theory, we present the novel idea to simulate a theory with four light and eight heavy flavors. Varying the mass of the heavy flavors, the theory changes from conformal to confining allowing us to demonstrate the walking nature of the running coupling as a function of the mass of the eight heavier flavors.

Nonzero temperature and Density / 369

Chiral transition as Anderson transition

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At low temperature the low-lying QCD Dirac spectrum obeys random matrix statistics. Recently we found that above T_{c} the lowest part of the spectrum consists of localized modes that obey Poisson statistics. An interesting implication of this is that as the system crosses T_{c} from above, the spectral statistics at $\lambda=0$ changes from Poisson to random matrix. Here we study this transition and its possible implications for the finite temperature transition of QCD-like theories.

Poster session - Board 21 / 370

Lattice calculation of neural network of theta neuron

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Neurophysics is a relatively new science. We will use quantum field theory to analyze the neural network of theta model. With a special lattice, one can explore the short term memory using lattice field theory calculation. Here we will theoretically show the path integral formalism which can be used to do perturbation theory. Simple lattice simulation will be conducted to compare with the theoretical analysis.

Hadron spectroscopy and interaction / 371

Investigation of the tetraquark candidate a_0(980): preliminary results

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We carry out a study of the light scalar meson a_0(980) employing interpolating field operators of quark-antiquark, diquark-antidiquark, mesonic molecules and two-particle meson operators. Both connected and disconnected quark loops are investigated. We present preliminary results for two ensembles of 2+1 clover fermion gauge configurations generated by the PACS-CS collaboration with pion masses ~300 MeV and ~150 MeV.

Hadron Structure / 372

Electric polarizability of neutral hadrons from dynamical lattice QCD ensembles

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Knowledge of the electric polarizability is crucial to understand the interactions of hadrons with electromagnetic fields. The neutron polarizability is very sensitive to the quark mass and is expected to diverge in the chiral limit. Here we present results for the electric polarizability of the neutron, neutral pion, and neutral kaon on eight ensembles with nHYP-smeared clover dynamical fermions with two different pion masses (227 and 306 MeV). These are currently the lightest pion masses used in polarizability studies. For each pion mass we compute the polarizability at four different volumes and perform an infinite volume extrapolation for the three hadrons. Along with the infinite volume extrapolation we conduct a chiral extrapolation for the kaon polarizability to the physical point. We compare our results for the neutron polarizability to predictions from chiral perturbation theory.

Weak Decays and Matrix Elements / 373

The B -> pi l nu and B_s -> K l nu form factors from 2+1 flavors of domain-wall fermions and relativistic b-quarks

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We report results for the B→π and B_s→K semileptonic form factors using lattice QCD with domain-wall light quarks and relativistic b-quarks. We use the 2+1 flavor domain-wall Iwasaki gauge configurations generated by the RBC and UKQCD collaborations at two lattice spacings of a~0.08fm and a~0.11fm. Our lightest pion mass is about 290MeV. We perform the chiral and continuum extrapolations using hard-pion SU(2) chiral perturbation theory, and extrapolate the form factors to the full kinematic range using the model independent z-expansion. Finally, we fit the numerical lattice data for B -> pi simultaneously with the experimental measurements from BaBar and Belle to obtain the CKM matrix element |V_{ub}|.

Poster session - Board 1 / 374

ContinuousBeta

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Reverse Monte Carlo, by Mak and Sharma, is a technique that allows for stochastic modification of the action of a lattice theory, while respecting the detailed balance condition of the original action. This modification of the action may permit more efficient
evolution of modes with large autocorrelation times. The classic
Swendsen and Wang cluster algorithm for the Ising model is in fact a
special case of Reverse Monte Carlo, where the action is modified
by stochastically deleting certain bonds (i.e. nearest neighbor interaction terms), resulting in cluster decomposition that allows for large scale updates removing critical slowing down. In this work, Reverse Monte Carlo is generalized to a method which allows for continuous change of the couplings in the action. We test the effectiveness of this new approach on the Ising model and an SU(3) pure gauge theory.

Weak Decays and Matrix Elements / 375

$B\to\pi$ semileptonic form factors from unquenched lattice QCD

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We update the lattice calculation of the $B\to\pi$ semileptonic form factors with a focus on the applications to the CKM matrix element $|V_{ub}|$. We use the MILC AsqTad 2+1-flavor lattice configurations at four lattice spacings and compute the matrix elements using the full-QCD valence quarks. We extrapolate the lattice data to continuum physics using the staggered chiral perturbation theory in the hard pion and SU(2) limit. We use a functional method to do the model-independent z expansion of the lattice extrapolation which extends the result to the full kinematic range. To obtain $|V_{ub}|$, we simultaneously fit the most recent experimental measurements from BaBar and Belle with our lattice result. The updated value of $|V_{ub}|$ and its error budget are presented.

Weak Decays and Matrix Elements / 376

Matrix elements for D-meson mixing from 2+1 lattice QCD

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We present the status of our calculation of the D-meson mixing hadronic matrix elements for all five short-distance operators. We use the $N_{f}=2+1$ asqtad gauge field ensembles generated by the MILC collaboration involving four lattice spacings ranging from 0.12 to 0.045 fm and up/down to strange quark mass ratios as low as 0.05. For the charm quark we use the Sheikholeslami-Wohlert action with the Fermilab interpretation. The valence quarks include the full-QCD point and up to seven partially-quenched points. The matrix elements are extrapolated to the physical point using SU(3) heavy meson staggered chiral perturbation theory. We present preliminary chiral and continuum extrapolated results for all five local operators as well as a full error budget.

Nonzero temperature and Density / 377

Gluonic Correlations at Deconfinement

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We investigate the critical behavior of electric and magnetic gluon propagators around the deconfinement temperature of SU(2) gauge theory on large lattices, employing Landau gauge. In particular, we study the analytic properties of these propagators using several trial fitting functions.

Poster session - Board 7 / 378

Evidence of BRST-Symmetry Breaking in Lattice Minimal Landau Gauge

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By evaluating the so-called Bose-ghost propagator, we present the first numerical evidence of BRST-symmetry breaking in minimal Landau gauge, i.e. due to the restriction of the functional integration to the first Gribov region in the Gribov-Zwanziger approach. We find that our data are well described by a simple fitting function, which can be related to a massive gluon propagator in combination with an infrared-free (Faddeev-Popov) ghost propagator. As a consequence, the Bose-ghost propagator, which has been proposed as a carrier of the confining force in Yang-Mills theories in minimal Landau gauge, presents a 1/p^4 singularity in the infrared limit.

Nonzero temperature and Density / 379

Shear Viscosity from Lattice QCD

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This talk is on recent efforts to determine the shear viscosity η in the deconfined phase from lattice QCD. The main focus is on the integration of the Wilson flow in the analysis to get a better handle on the infrared behaviour of the spectral function which is relevant for transport. Also the non-perturbative renormalization strategy applied for the energy momentum tensor is discussed. At the end some quenched results for temperatures up to $4.5T_c$ are presented.

Weak Decays and Matrix Elements / 380

Lattice Measurement of the Delta I=1/2 Contribution to Standard Model Direct CP-Violation in K->pi pi Decays at Physical Kinematics: Part I

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The RBC & UKQCD collaborations have recently published lattice results for the K->pi pi decay amplitude in the I=2 channel, A_2, and improved results will be presented at this conference. In this presentation we discuss the determination of the I=0 channel amplitude, A_0. Combining this with A_2 provides epsilon', the measure of direct CP-violation in the Standard Model. In part I we provide an overview of the project and detail our use of G-parity boundary conditions to achieve physical kinematics in the decay, as well as discussing the ongoing generation of the specialized lattices required.

Nonzero temperature and Density / 382

Thermodynamics of heavy-light hadrons

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Ratios of cumulants of conserved net charge fluctuations are sensitive to the degrees of freedom that are carriers of the corresponding quantum numbers in different phases of strong interaction matter. We calculate second and fourth order cumulants of net charm and strange fluctuations and their correlations with other conserved charges such as net baryon number and electric charge.

Simulation are performed on Nt=6,8,12 lattices using the Highly Improved Staggered Quark (HISQ) action with a light to strange quark mass ratio of 1/20 and having charm quarks treated in the quenched approximation.

Analyzing appropriate ratios of these cumulants we observe that both open strange and charm hadrons start to get deconfined in the chiral crossover region. We provide evidence for additional, experimentally yet unobserved open charm and strange hadrons from QCD thermodynamics by comparing lattice QCD results to Hadron Resonance Gas model calculations performed with a hadron spectrum as listed in the Particle Data Tables as well as with a spectrum predicted in relativistic quark model and observed in lattice QCD calculations.

We also discuss the influence of these yet unobserved states on the determination of freeze-out temperature and chemical potentials from heavy ion collision experiments.

Vacuum Structure and Confinement / 383

The Gluon Dyson-Schwinger equation of Lattice Landau Gauge

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We investigate the exact gluonic Dyson-Schwinger equation of quenched SU(n) lattice gauge theory in Landau gauge and the lattice analog of the
Kugo-Ojima confinement criterion.

Nonzero temperature and Density / 384

QCD with Wilson fermions and isospin chemical potential at finite and zero temperature

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We study QCD with Wilson fermions in the presence of an isospin chemical potential mu_I.
At zero temperature, condensation of iso-positive pions is expected to occur as soon as mu_I reaches half the pion mass.
By looking at the isospin density and the mass spectrum of mesons as a function of mu_I, we investigate this pion condensation on the lattice and extend the study to non-zero temperature.
By increasing mu_I further, we also look for a possible condensation of additional mesons and for a saturation transition.

Hadron Structure / 385

Radiative Physics on the Lattice using Distillation

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We present a progress update on an ongoing calculation aimed at extracting photocouplings in the light-quark sector from radiative matrix elements computed using lattice QCD. These couplings drive the rate of photo production of mesons, of particular interest are exotic and hybrid mesons which while present in lattice calculations have yet to be observed experimentally. The use of distillation in conjunction with a large variational basis of interpolating operators allows for efficient extraction of signals from three-point functions making such calculations possible. Preliminary results for excited state light quark transition form factors will be presented.

Theoretical Developments / 386

Causal Space-Time on a Null Lattice with Hypercubic Coordination

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I discuss the discretization of causal space-times on a topological lattice of events with hypercubic coordination whose links are light-like. Conditions that ensure this lattice is the discretization of a causal manifold are derived. They are encoded by a local topological lattice theory which has a particularly simple and appealing form when null-coframes are represented by spinors.

Hadron Structure / 387

The leading hadronic contribution to (g-2) of the muon: The chiral behavior using the mixed representation method

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We extend our analysis of the leading hadronic contribution to the anomalous magnetic moment of the muon using the mixed representation method to approach the physical point. We present results derived from local-conserved two-point lattice vector correlation functions, computed on a subset of light two-flavor ensembles made available to us through the CLS effort with pion masses as low as 190MeV. The data is analyzed also using the more standard four-momentum method. Both methods are systematically compared as the calculations approach the physical point.

Weak Decays and Matrix Elements / 388

Lattice Measurement of the Delta I=1/2 Contribution to Standard Model Direct CP-Violation in K->pi pi Decays at Physical Kinematics: Part II

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In continuation of part I, I will discuss our use of all-to-all propagators in order to construct pi-pi operators with reduced coupling to the vacuum, which helps to reduce the noise in the K->pipi(I=0) decay amplitude. I will also present preliminary results for the pipi(I=0) phase shift, decay amplitude A_0, both with physical kinematics. The precise value of A_0, once computed, will provide the measure of direct CP-violation epsilon prime, on the lattice.

Nonzero temperature and Density / 389

The Combinatorics of Lattice QCD at Strong Coupling

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We compare the combinatorics of staggered and Wilson fermions in the strong coupling limit for various colors and flavors. Based on the hopping parameter expansion, we express the partition functions of both discretizations in terms of polynomials with coefficients of distinct combinatorical interpretation.

We address how gauge corrections to the strong coupling limit modify the combinatorics and possibly make both lattice discretizations more similar in the continuum limit.

We compare our analytic results by some recent numerical findings obtained at finite temperature and density.

Application beyond QCD / 390

Glueball masses in 2+1 dimensional SU(N) gauge theories with twisted b.c.

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We analyze 2+1 dimensional Yang-Mills theory regularized on a lattice with twisted boundary conditions in the spatial directions. In previous work it was shown that the observables in the non-zero electric flux sectors obey the so-called x-scaling, i.e. depend only on the variable x~NL/b and the magnetic flux, given by the parameters of the twist (L being the length of the spatial torus and b the inverse 't Hooft coupling). It is conjectured that this scaling is obeyed by all physical quantities. In this work we extend the previous analyses to the zero-flux (glueball) sector. We study the x-scaling conjecture in this sector from the perturbative small-volume regime to the non-perturbative one.

Hadron Structure / 391

Nucleon axial form factors from two-flavour Lattice QCD

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We present preliminary results on the axial form factor G_A(Q^2) and the induced pseudo-scalar form factor G_P(Q^2) of the nucleon. The relevant matrix elements were computed on CLS ensembles with N_f =2 non-perturbatively improved O(a) Wilson fermions at three lattice spacings, namely a = 0.050, 0.063, 0.079 fm. These calculations were performed with pion masses ranging from as low as m_pi = 195 MeV to m_pi = 473 MeV with box lengths ranging from L = 2.4 - 4 fm and up to a total of 4000 measurements on each ensemble. A systematic study of the contribution of excited states is performed by analysing the relevant matrix elements at several source-sink separations. Preliminary results on the axial radius r^2_A are also presented.

Algorithms and Machines / 392

Diffusion of topological charge and scaling of autocorrelation times in hybrid Monte Carlo simulations of lattice QCD

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We determine the scaling behavior of the autocorrelation times of observables constructed from the topological charge density on lattices with periodic and open boundary conditions using a series of high-statistics numerical simulations. The autocorrelation functions of such observables turn out to obey a simple differential equation which allows the motion of topological charge in hybrid Monte Carlo simulations to be understood in terms of only two processes: diffusion and tunneling. There is a characteristic lattice spacing at which open boundary conditions become worthwhile for reducing autocorrelations and we show how this lattice spacing is related to the diffusion constant, the tunneling rate, and the lattice Euclidean time extent.

Nonzero temperature and Density / 393

The QCD Equation of State at order μ_B^4

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Hydrodynamic models of heavy-ion collisions have increasingly begun to rely on lattice results for the Equation of State. While the lattice has the advantage of being a first-principles approach to QCD, the notorious sign problem prevents a direct determination of the equation of state and other thermodynamic observables at finite chemical potential μ_B.

Quark number susceptibilities allow us to extrapolate the equation of state in a controlled way to small values of μ_B based on calculations at $\mu_B=0$. Such an extrapolation is necessary in order to accurately describe the results from the beam energy scan at RHIC and from the LHC where typically $\mu_B/T=0.1$-4, depending upon the energy of the beam.

In our talk, we will present results from a high-statistics calculation of all the Taylor coefficients upto sixth order in a (μ_B,μ_Q,μ_S)-expansion of the pressure. Our calculation allows us to extrapolate, for the first time, the equation of state on the freezeout curve upto $\mathcal{O}(\mu_B^4)$ while our sixth-order results show that the truncation error is not more than a few \% upto $\mu_B/T\sim1.5$. Thus our equation of state should be useful in describing both the LHC results as well as results from RHIC beam energy scan down to $\sqrt{s}\sim$20 GeV. We will also use our results to construct the isentropic equation of state for strangeness-neutral systems.

Our lattice QCD calculations make use of the gauge ensembles generated using the HISQ action. Our lattices sizes range from 6×24^3 to 12×48^3 and the pion mass ($\sim$160 MeV) is nearly equal to its physical value while the strange quark is at exactly its physical value.

Hadron spectroscopy and interaction / 394

Generating 2+1+1 Flavor Mobius Domain Wall Fermion Configurations

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The RBC and UKQCD Collaborations are generating 2+1+1 flavor Mobius domain wall fermion configurations with $1/a = 3$ and 4 GeV. To achieve good topological tunneling at these weaker couplings, the gauge action is the Wilson action plus a Dislocation Enhancing Determinant (DED) term. The DED term enhances the probability of gauge fields where toplogy-changing dislocations are present, through the inverse of the effect produced by the Dislocation Suppressing Determinant Ratio (DSDR) we have employed in strong coupling domain wall fermion simulations. Tests and consequences of the DED term will be discussed and some preliminary results of measurements on these lattices will be given.

Nonzero temperature and Density / 395

Search for the chiral phase transition in three flavor QCD at imaginary chemical potential

Dr. TOTH, Balint [1]; Dr. BORSANYI, Szabolcs [2]; Prof. SZABO, Kalman [3]; Mr. TROMBITAS, Norbert [4]; Dr. DURR, Stephan [1]; Prof. FODOR, Zoltan [1]; Dr. HOELBLING, Christian [1]; Prof. KATZ, Sandor [4]; Dr. KRIEG, Stefan [5]; Dr. NOGRADI, Daniel [6]; Mr. PASZTOR, Attila [7]

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The finite temperature transition of QCD with three degenerate flavors is expected to become a first order phase transition at small quark masses. It has been observed that introducing a sufficiently large imaginary chemical potential broadens the first order region and raises the critical quark mass to the numerically feasible regime. We report on our search for this first order transition at imaginary chemical potentials using three flavors of staggered quarks.

Vacuum Structure and Confinement / 396

Magnetic monopole and confinement/deconfinement phase transision in SU(3) Yang-Mills theory

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We have proposed the non-Abelian dual super conductivity in SU(3) Yang-Mills (YM) theory for the mechanism of quark confinement, and by using the proposed gauge link decomposition to extract magnetic monopole in the gauge invariant way we presented the evidences in lattice conferences.

In this talk, we focus on the dual Meissner effects in view of the magnetic monopole in SU(3) Yang-Mills theory. We measure the chromo-electric and chromo-magnetic flux due to a pair of quark and antiquark source at finite temperature. Then, we measure the correlation function of Polyakov loops and Polyakov loops for various temperatures, and investigate chromo-magnetic monopole current induced by chromo-magnetic flux in both confinement and deconfinement phase. We will discuss the role of the chromo-magnetic monopole in confinement/deconfinement phase transition.

Algorithms and Machines / 397

Adaptive Multigrid Solvers for LQCD on GPUs

Prof. BROWER, Richard [1]; Dr. CHENG, Michael [1]; Dr. CLARK, M [2]

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There has been much progress to date in developing scalable sparse linear solver algorithms on GPUs, utilizing well-known mathematical methods such as mixed precision, domain decomposition and pipelining to improve performance, allowing efficient use of large GPU installations such as Blue Waters and Titan. However, there has been less focus on deploying 'mathematically optimal' linear solvers, that have optimal O(N) complexity. In this work we utilize the QUDA framework to deploy adaptive multigrid solvers on GPUs, in particular we describe the architecture abstractions that allow for deployment on heterogeneous systems, utilizing both GPUs and CPUs. We discuss in general the suitability of heterogeneous architectures for hierarchical algorithms, and compare performance against a highly optimized CPU implementation.

Nonzero temperature and Density / 398

The QCD Equation of State

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The HotQCD Collaboration has calculated the equation of state in 2+1 flavor QCD at zero net baryon density using the Highly Improved Staggered Quark (HISQ) action. The
strange quark mass was set to its physical value and the light (up/down)
quark masses used correspond to a pion mass of 160 MeV in the continuum
limit. Lattices with temporal extent Nt=6, 8, 10 and 12 were used, and the cutoff effects for Nt>6 were observed to be quite small. For temperatures
in the range 130 MeV < T < 400 MeV continuum extrapolations were performed. We will discuss errors and compare our results with others in the literature.

Nonzero temperature and Density / 399

Dirac eigenmodes at the QCD Anderson transition

Prof. KOVACS, Tamas G. [1]; Dr. GIORDANO, Matteo [2]; Dr. PITTLER, Ferenc [3]; Mr. UJFALUSI, Laszlo [4]; Dr. VARGA, Imre [4]

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Recently we found an Anderson-type localization-delocalization transition in the QCD Dirac spectrum at high temperature. Using spectral statistics we obtained a critical exponent compatible with that of the corresponding Anderson model. Here we study the spatial structure of the eigenmodes both in the localized and the transition region. Based on previous studies in the Anderson model, at the critical point, the eigenmodes are expected to have a multifractal structure.

Hadron Structure / 400

Perturbative reweighting, dilution, and low mode substitution for sea quark contribution to the neutron polarizability

Dr. FREEMAN, Walter [1]; Prof. ALEXANDRU, Andrei [1]; Prof. LEE, Frank X. [1]; Mr. LUJAN, Michael [1]

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The contribution of the sea quark charges is a large uncertainty in lattice calculations of hadron polarizabilities; we present an update in our use of perturbative reweighting in the quark charge to address this issue. The difficult aspect of this calculation is the stochastic estimation of the weight factor expansion coefficients. We use aggressive (large-N) dilution, consisting of body-centered (hyper)cubic spatial dilution in addition to spin/color dilution, to minimize the contribution of large near-diagonal elements to the estimator variance. We will present results from this technique applied to our smallest-volume ensemble. For a larger ensemble we have developed a variant of low-mode subtraction in which low modes of \gamma_5 D are treated separately; this further reduces the estimator variance by an order of magnitude. We will discuss the various stochastic estimator improvement techniques and present in-progress results from the new calculation.

Nonzero temperature and Density / 401

Effects of an external magnetic field on the QGP

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We present results for the pressure of the quark-gluon plasma in the presence of a strong magnetic filed, calculated using a Taylor expansion in the field to 4th order.
Our method does not require quantization of the magnetic filed and is computationally cheaper than calculations on ensembles generated with explicit magnetic fields.

Hadron Structure / 402

Disconnected contribution to the nucleon charges from N_f = 2+1+1 lattice QCD

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We calculate the disconnected contribution to the nucleon isoscalar charges of the scalar, axial and tensor channels of light quarks. The calculation has been done by using the Clover valence quarks on the MILC N_f=2+1+1 HISQ lattice at a lattice spacing of 0.12 fm and light quark mass corresponding to the pion mass of 310 MeV. Two-point correlators are evaluated from 60 sources distributed in four timeslices. Disconnected quark loops are estimated by using the truncated solver method with 5000 Gaussian random noise sources. Multigrid inverter is used both for the two-point correlators and the disconnected quark loops. Contamination from the excited states is removed by simultaneously fitting the results of various source-sink separations and operator insertions to the formula including the first excited state. These are applicable to the calculation of other physical observables such as the neutron electric dipole moment and the transverse momentum distribution functions.

Algorithms and Machines / 403

The FUEL code project

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I will give an introduction to the FUEL project for lattice field theory code. The code being developed (called "qhmc") was initially targeted for gauge field generation for beyond standard model theories, and is now growing into a more general framework suitable for analysis too. The design is based on using the Lua scripting language as a wrapper for existing lattice field theory libraries, which provides a quick and easy way to develop new calculations. The implementation currently only supports the USQCD QOPQDP and QDP/C libraries, with support for other optimized libraries planned. I will discuss the current status of the code along with future plans for development.

Physics beyond the standard model / 404

Testing composite Higgs models on the lattice

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Composite Higgs dynamics due to a new gauge sector has recently attracted renewed interest both phenomenologically and on the lattice. In fact, while a scalar particle consistent with the Standard Model Higgs has been discovered at the LHC, the detailed nature of this particle remains unknown. One popular description is that the Higgs is a result of a strongly coupled composite framework, such as models based on the SU(4)/Sp(4) coset. One fundamental theory that yields this coset is an SU(2) gauge theory with 2 flavors in the fundamental representation. We study the spectrum of this theory on the lattice and look at the flavor-singlet scalar channel, where the Higgs particle could emerge as an excitation of the fermion condensate.

Hadron spectroscopy and interaction / 405

Multi-channel 1 to 2 matrix elements in finite volume

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We derive a model-independent expression for finite-volume matrix elements. Specifically, we present a relativistic, non-perturbative analysis of the matrix element of an external current between a one-scalar in-state and a two-scalar out-state. Our result, which is valid for energies below higher-particle inelastic thresholds, generalizes the Lellouch-Luscher formula in two ways: we allow the external current to inject arbitrary momentum into the system and we allow for the final state to be composed an arbitrary number of strongly coupled two-particle states with arbitrary partial waves (including partial-wave mixing induced by the volume). We also illustrate how our general result can be applied to some key examples, such as heavy meson decays and meson photo production.

Poster session - Board 48 / 406

Neutron-Antineutron Operator Renormalization

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Neutron-antineutron oscillation is a baryon number violating process that is predicted to occur in many theories of physics beyond the standard model. To make quantitative predictions that can be compared to experiment, matrix elements of six-quark effective operators must be computed via lattice QCD and must also be connected to continuum beyond the standard model operators. We present preliminary work on computing operator renormalization and lattice-continuum matching factors to facilitate this connection for neutron-antineutron oscillation operators.

Physics beyond the standard model / 407

Spectrum of the SU(4) lattice gauge theory with fermions in the anti-symmetric two index representation

Dr. LIU, Yuzhi [1]; Prof. DEGRAND, Thomas [2]; Prof. NEIL, Ethan [1]; Dr. SHAMIR, Yigal [3]; Dr. SVETITSKY, Benjamin [3]

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We study the SU(4) lattice gauge theory with Nf=2 Dirac fermions in the anti-symmetric two index (sextet) representation (the ``SU(4)/sextet" theory). This is a real fermion representation, which allows simulation at non-zero chemical potential with no sign problem. In addition, ``SU(4)/sextet" is an interesting generalization of QCD, allowing direct exploration of an alternate large-N_c expansion with fermions in the sextet representation. In this talk, I will present our preliminary results on the baryon and meson spectrum of the theory and compare them with SU(3) results and large-N_c scaling.

Physics beyond the standard model / 408

Beyond the Standard Model Kaon Mixing from Mixed-Action Lattice Simulations

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We calculate matrix elements for beyond-the-Standard-Model contributions to neutral kaon mixing from mixed-action lattice simulations with staggered sea quarks and domain-wall valence quarks. We analyze the (2+1)-flavor MILC asqtad ensembles with multiple light sea-quark masses corresponding to staggered pions as light as 220 MeV on three different lattice spacings a ~ 0.12, 0.09, and 0.06 fm, and extrapolate our data to the physical light-quark masses and continuum using mixed-action chiral perturbation theory. We renormalize the matrix elements using mean-field improved lattice perturbation theory at one loop to obtain continuum values in the MS-bar scheme. Once our analysis is finalized, our results will help to improve constraints on new physics from experimental measurements of neutral kaon mixing.

Weak Decays and Matrix Elements / 409

The Kaon Semileptonic Form Factor from Domain Wall QCD at the Physical Point

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We present an update on the RBC/UKQCD collaboration's calculation of the kaon semileptonic form factor at zero momentum transfer, $f_{+}^{K \pi}(0)$. This calculation utilizes two new $N_{f} = 2+1$ M\"{o}bius Domain Wall Fermion ensembles which allow us to simulate QCD directly at physical pion mass for the first time. Together with our previous results we now have a complete set of measurements extending from the $SU(3)$ symmetric limit down to the physical point, allowing us to minimize systematic error associated with the chiral extrapolation.

Poster session - Board 44 / 410

Exploring the phase structure of 12-flavor SU(3)

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We are studying the SU(3) gauge theory with 12 staggered fermions, searching for the endpoint of the line of first-order phase transitions in the mass-beta plane. This endpoint plays an important role in our understanding of the phase diagram of this model. Having found this endpoint with high statistics on a small lattice using unimproved staggered fermions, we are working to find it on larger lattices with improved actions. For an action improved with nHYP-smeared staggered fermions, we discuss the effect of slowly turning off the improvement on the broken shift symmetry phase.

Algorithms and Machines / 411

Application of Adaptive Multigrid Algorithm in Hybrid Monte Carlo Simulations

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Lattice QCD has entered the era of simulations directly at the physical quark masses thanks to the increasing computing power and algorithmic advancement. But the computational cost for such simulations is still extremely high, both for the gauge field generation and the measurements of physical observables. Adaptive multi grid (MG) algorithm has proven to be quite effective in reducing the computational cost in measurements with Wilson-type fermions, provided that many measurements are performed on one gauge configuration due to the high setup cost for MG. We explore the feasibility of applying the multi grid algorithm in the hybrid Monte Carlo simulations with Wilson fermions, and show some preliminary results.

Vacuum Structure and Confinement / 412

Deconfinement, Chiral Symmetry Breaking and Chiral Polarization

Prof. HORVATH, Ivan [1]; Prof. ALEXANDRU, Andrei [2]

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We examine the feasibility of the proposition that in Nf=0 QCD there is a temperature range (T_c < T < T_ch) where real Polyakov line (deconfined) vacuum exhibits valence spontaneous chiral symetry breaking and dynamical chiral polarization of Dirac eigenmodes.

Hadron Structure / 413

Initial nucleon structure results with chiral quarks at the physical point

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[5] New Mexico State University

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I will report initial nucleon structure results computed on lattices with 2+1 dynamical Moebius domain wall fermions at the physical point generated by RBC and UKQCD. At this stage, we evaluate only connected quark contributions. In particular, I will discuss the nucleon electric and magnetic radii, quark contributions to the nucleon spin, the nucleon axial charge, and the quark momentum fraction. From the currently available statistics, we estimate that within a year our stochastic + excited states-systematic errors for the nucleon electric radius will approach the level of the discrepancy between the two experimental values. To reduce the computational cost of our calculations, we extensively use acceleration techniques such as low-eigenmode deflation and all-mode-averaging.

Poster session - Board 16 / 414

Conformality in twelve-flavor QCD

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The spectrum of twelve-flavor QCD has been studied in details by the LatKMI collaboration. Here we present our updated results obtained with the HISQ action at two lattice spacings, several volumes and fermion masses. We emphasize the existence of a flavor-singlet scalar state parametrically light with respect to the rest of the spectrum, first reported in our paper [1]. This feature is expected to be present in theories near the conformal window, but the lattice calculation of such a light state is difficult and requires noise-reduction techniques with large statistics, in order to evaluate disconnected diagrams. Being able to provide a robust observed connection between a light flavor-singlet scalar and near-conformality is an important step towards observing a light composite Higgs boson in walking technicolor theories [2]. Updated spectrum in the other channels is also presented.

[1] LatKMI Collaboration, "Light composite scalar in twelve-flavor QCD on the lattice", PhysRevLett.111.162001
[2] LatKMI Collaboration, "Light composite scalar in eight-flavor QCD on the lattice", arxiv:1403.5000

Weak Decays and Matrix Elements / 416

B meson decay constants and Delta B=2 matrix elements with static heavy and doma in-wall light quarks

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Neutral B meson mixing matrix elements and B meson decay constants are calculated. Static approximation is used for b quark and domain-wall fermion is employed for light quarks. The calculations are carried out on Nf=2+1 dynamical ensembles with lattice spacings of 0.086fm and 0.11fm, and a fixed physical spatial volume of about (2.7fm)^3, generated by RBC/UKQCD Collaborations. We employ two kinds of link-smearing and their results are combined in taking a continuum limit. For the matching between the lattice and the continuum theory, one-loop perturbative O(a) improvements are made to reduce discretization errors. We also show statistical improvements by the all-mode-averaging technique.

Hadron spectroscopy and interaction / 417

Two-Baryon Systems with Twisted Boundary Conditions

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We explore the use of twisted boundary conditions in extracting the nucleon mass and the binding energy of two-baryon systems, such as the deuteron, from Lattice QCD calculations. Using the experimentally determined phase shifts and mixing angles, and utilizing the Luescher method extended to baryonic systems with twisted boundary conditions, we determine the expected energies of the deuteron states over a range of cubic lattice volumes for a selection of twisted boundary conditions. Certain choices of twist angles, as well as selected pair-wise averages, improves the volume dependence of the deuteron binding energy. The set of energy quantizations conditions obtained adds to the previously determined conditions with arbitrary center of mass momenta and is shown to be valuable in constraining the deuteron binding energy and S-D mixing parameter from upcoming lattice QCD calculations of two-nucleon systems at the physical light-quark masses.

Vacuum Structure and Confinement / 418

Zero modes of overlap fermions, instantons and monopoles

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Monopoles are considered that play the very important roles for the color confinement mechanism. University of Kanazawa and Pisa groups have shown a number of studies which support the confinement mechanism due to monopole condensations by the lattice simulations.
Instantons that are other topological objects found as solutions of QCD. The close relations to chiral symmetry breaking are theoretically explained, moreover, the relations are revealed by numerical simulations. The purpose of our study is to show that monopoles relate to instantons and chiral symmetry breaking by using the overlap fermions as an analytical tool.
To show the relations, first we generate SU(3) configurations for Wilson gauge action. We construct the overlap Dirac operator from link variables of the configurations, solve the eigenvalue problems by using of the subroutines (ARPACK), and find O(80) pairs of eigenvalues and eigenvectors each configurations. We count the number of the zero modes each ensemble. After analytical computations, we confirm that the instanton density is consistent with the instanton liquid model by E. V. Shuryak. Second, we add monopoles and anti-monopoles with several charges to SU(3) configurations for Wilson gauge action by the monopole creation operator which is defined by the University of Pisa group. Third, we fix the maximally abelian gauge. After performed the abelian projection we localize the monopoles on the lattice. We measure the length of monopole loops and the monopole density to confirm that the monopoles are successfully added by the monopole creation operator. The last, we diagonalize the overlap Dirac operator deriving from the configurations which the monopoles are added. We try to quantitatively verify how many the monopoles with charges make the zero modes (instantons) in order to show the relations between them.
In my talk, I would like to present our preliminary results.

Physics beyond the standard model / 419

Higgs physics near the conformal window

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We will use the minimal composite Higgs model to discuss theoretically and phenomenologically important issues imposed on the low mass near-conformal composite scalar of BSM Higgs physics.

Nonzero temperature and Density / 421

Fluctuation effects on QCD phase diagram at strong coupling

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We investigate QCD phase diagram at strong coupling based on strong coupling expansion in auxiliary field Monte-Carlo (AFMC) method. The strong coupling expansion is one of the ways to reduce the sign problem since the effective action is described in hadronic degrees of freedom via analytic integration over link variables.
We have found that hadron phase is compressed (extended) at low (high) chemical potential [1] as shown in monomer-dimer-polymer simulation [2] in the strong coupling limit (SCL). We need to consider finite coupling effects to know the influence on phase diagram and the sign problem. The AFMC is a natural extension to the mean field method, which let us include finite coupling and fluctuation effects straightforwardly.
In the presentation, we will give some results on QCD phase diagram in SCL. We will also discuss next-to-leading order effects in the strong coupling expansion.

[1] T. Ichihara, A. Ohnishi, T. Z. Nakano, arXiv:1401.4647 [hep-lat]. [2] W. Unger, P. de Forcrand, J. Phys. G38 (2011) 124190.

Chiral Symmetry / 422

Individual eigenvalue distributions for chGSE-chGUE crossover and determination of low-energy constants in two-color QCD+QED

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We evaluate the individual distributions of four smallest eigenvalues from chiral random matrix ensembles interpolating chGSE and chGUE by the quadrature method applied to the Fredholm Pfaffian of dynamical Bessel kernel containing a crossover parameter. These distributions are then fitted with the staggered Dirac spectra of the quenched SU(2) lattice gauge theory in the presence of fluctuating or constant U(1) fields. Combination of the four best-fitting crossover parameters from matching each random matrix theory prediction to the corresponding histogram of the k-th Dirac eigenvalue allows for an efficient and precise determination of low-energy constants F and \Sigma in the chiral Lagrangian of Nambu-Goldstone bosons on the coset space SU(2n)/Sp(2n) from relatively small lattices.

Nonzero temperature and Density / 423

Solution of simple toy models via thimble regularization of lattice field theory

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The sign problem prevents lattice simulations of many models of physical interest. One proposal for evading such problems is the thimble regularization. I will discuss its application to the phi^4 0-dimensional integral, which is a toy model that has been studied for many years as a prototype of complex-valued action and raises several problems within a treatment via complex Langevin; this model can be successfully solved with the thimble approach, though it exhibits a very non trivial structure. I will discuss the details of the thimble structure in this model along with three different algorithms that we have used to get precise numerical results. I will also briefly outline some preliminary results concerning the application of the thimble approach to a Chiral Random Matrix model, which has been recently discussed in the literature and has proved to be problematic for complex Langevin.

Algorithms and Machines / 424

An algorithm for thimble regularization of lattice field theories (and possibly not only for that)

Dr. DI RENZO, Francesco [1]; Dr. GIOVANNI, Eruzzi [1]; Dr. BRAMBILLA, Michele [2]

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In the context of thimble regularization of lattice field theories we are developing a new simulation algorithm. The main difficulty is to devise a sampling of configurations on a non-trivial manifold, which is defined as the hypersurface formed by the union of all paths of steepest descent of the complex action ending in a given saddle point. The main point with the new algorithm is the one-to-one correspondence of configurations and action values on a given steepest descent curve, which can in turn be seen as a steepest ascent if one changes the sign of the "time" variable.
We discuss the possible extensions of the algorithm to more general field theories. In the context of Lattice QCD the possible main advantage could be a mitigation of the problems connected to different topological sectors.

Standard model parameters and renormalization / 425

An update on the status of NSPT computations

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In recent years Numerical Stochastic Perturbation Theory (NSPT) has proven to be a viable tool to perform perturbative computation at high order on the lattice. Despite final results are equivalent to standard Feynman diagrams the approach is rather different and allows a numerical implementation similar to usual (nonperturbative) MonteCarlo.
I will discuss final results for the computation of renormalization constants of quark bilinears for the regularizations defined by nf=2 Wilson fermions/tree level Symanzik improved gauge and nf=4 Wilson fermions/Iwasaki improved gauge. NSPT results will be compared with the ones coming from non perturbative determinations. I will also discuss current developments in the context of clover fermions.

Hadron Structure / 426

Lattice Calculation of the Hadronic Light by Light Contributions to the Muon Anomalous Magnetic Moment

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The anomalous magnetic moment of muon, g-2, is a very precisely measured quantity. However, the current measurement disgrees with standard model by about 3σ. Hadronic vaccum polarization and hadronic light by light are the two types of processes that contribute most to the theorectial uncertainty. We will discuss the light by light lattice calculation and some strategies of including QED on lattice.

Nonzero temperature and Density / 428

The QCD Phase Transition with Three Physical-Mass Pions

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On behalf of the HotQCD collaboration, I present results from the first lattice study of the QCD phase transition using chiral fermions and physical quark masses. With domain wall fermions, the dislocation suppressing determinant ratio (DSDR), a temporal Euclidean extent of 8 sites, and spatial extents of at least 4 and up to 11 fm, we have computed the disconnected chiral susceptibility for several temperatures between 130 and 200 MeV and found a pronounced peak, the position and height of which depend sensitively on the quark mass. We find no metastability in the peak region and no significant change in the peak height upon increasing the spatial extent from 5 to 10 fm, strong evidences that the transition is an analytic crossover. We derive a pseudo-critical temperature of 155(1)(8) MeV and find that while chiral symmetry is fully restored above 164 MeV, anomalous $U(1)_A$ symmetry breaking is substantial until roughly 196 MeV. In addition, I present preliminary results for our latest calculation with a temporal extent of 12 sites, aimed at quantifying finite lattice spacing effects.

Poster session - Board 37 / 429

Improved statistics of proton decay matrix element

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We report our recent study of proton and neutron decay matrix element
with highly improved statistics using all-mode-averaging technique.
On 2+1 flavor domain-wall fermion configurations, we obtain accurate
proton to pseudoscalar (pion, K and eta) meson transition form factor.
In this report we also discuss the comparison with baryon chiral perturbation
in physical kinematics and estimate of improvement of GUT prediction.

Poster session - Board 14 / 430

Error reduction with all-mode-averaging in Wilson fermion

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We report preliminary result of all-mode-averaging technique in
Wilson fermion. On two-flavor CLS configurations, we compare the
performance to obtain high precision of nucleon form factor and
hadronic vacuum polarization function using truncated solver with deflated
SAP+GCR algorithm.

Poster session - Board 9 / 431

Correlation functions with Karsten-Wilczek fermions

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The explicit breaking of time-reflection symmetry in the Karsten-Wilczek action is hidden in various mesonic correlation functions that are calculated in the quenched approximation. Two underlying discrete product symmetries are discussed, which each allow for enforcement of time-reflection symmetry for correlation functions constructed according to additional symmetry requirements.

An additional non-perturbative tuning condition for the relevant fermionic counterterm is demonstrated and a comparison between two independent non-perturbative conditions with boosted perturbation theory is presented.

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Screening without dynamical quarks

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Screening of external charges by electric fluxes induced by periodic boundary conditions in two dimensional gauge theories will be discussed. Subsequently, the less known problem of introducing sources with arbitrary charge, i.e. non-congruent with an elementary one, will be presented and elaborated. Finally the new, classical continuum limit of lattice formulation will be proposed and shown to reproduce confining potential with an arbitrary classical charge. Connection with the massive Schwinger model will be also indicated.

Poster session - Board 15 / 433

The charmonium states X(3872)(1++) and Zc(3900)(1+-) on HISQ lattices

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We present preliminary simulation results for the I = 0 charmonium state X(3872)(1++) and the I = 1 charmonium state Zc(3900)(1+-). The study is performed on (2+1+1)-flavor highly improved staggered quark (HISQ) lattices with clover (Fermilab interpretation) charm quarks and HISQ light quarks. Since the X(3872) lies very close to the open charm D-bar-D* threshold, we use a combination of c-bar-c and D-bar-D* interpolating operators. For the Zc(3900) we use a combination of J/psi-pi and D-bar-D* channels.

This is the first such study with HISQ light valence quarks. To this end, we describe a variational method for treating staggered quarks that provides for both oscillating and non-oscillating components.

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van Baal's legacy: From renormalons to bions

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This talk presents a summary of our current understanding of confinement problem in non-abelian gauge theories. It is dedicated to the memory of Pierre van Baal, who contributed to the field significantly.

I will review recent semi-classically calculable realization of confinement in various gauge theories. In particular, I will describe the role of monopole-instantons(realized by van Baal), and their role in neutral and magnetic bions, and the relation of these semi-classical saddles to 't Hooft's elusive renormalon problem. The techniques I describe uses resurgence theory, and related Lefschetz thimble (homology cycle) decomposition of path integrals.

Hadron Structure / 436

Towards the large volume limit - An application to hadronic contributions to muon g-2 and EM corrections

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We explore ways to decrease parts of the finite volume error and apply the method to the hadronic contributions to muon g-2.

Hadron spectroscopy and interaction / 437

Conserved currents and results from 2+1f dynamical Mobius DWF simulations at the physical point

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We discuss the construction of the almost conserved axial and exactly conserved vector currents in the Mobius generalisation of DWF at finite Ls. I then report on the status of 2+1f DWF simulations at the physical point, with a focus on the determinations of the lattice spacings, and of the pion and kaon decay constants and the Kaon bag parameter in the continuum limit.

Application beyond QCD / 438

Numerical simulation of graphene in an external magnetic field

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The results of numerical simulation of graphene effective field theory in external magnetic field are presented. The numerical simulation is performed using noncompact (3+1)-dimensional Abelian lattice gauge fields and (2+1)-dimensional staggered lattice fermions. The dependences of fermion condensate and conductivity on the dielectric permittivity of the substrate for different values of external magnetic field are calculated. It is found that magnetic field shifts insulator-semimetal phase transition to larger values of the dielectric permittivity of the substrate. The phase diagram of graphene in external magnetic field is drawn.

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test

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Poster session - Board 43 / 440

Condensation in two flavor scalar electrodynamics with non-degenerate quark masses

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We explore two flavor scalar electrodynamics on the lattice, which has a complex phase problem at finite chemical potential. By rewriting the action in terms of dual variables this complex phase problem can be solved exactly. The dual variables are link- and plaquette occupation numbers, subject to local constraints that have to be respected by the Monte Carlo
algorithm. For the simulation we use a local update scheme.
Assigning two different fundamental masses to the two flavors of the underlying model we can achieve a mass splitting between the
single-flavor quark-antiquark bound states. We then introduce a finite chemical potential and study the particular characteristics of the systems condensation which we expect due to the mass splitting between the bound states.

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Poster session - Board 51 / 442

HISQ inverter on Intel Xeon Phi and NVIDIA GPUs

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Poster session - Board 52 / 443

High-Performance I/O: HDF5 for Lattice QCD

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Practitioners of lattice quantum chromodynamics (LQCD) have been some of the primary pioneer users of the state-of-the-art HPC systems, and contribute towards the stress tests of such new machines as soon as they become available. As with all aspects of HPC, I/O is becoming an increasingly specialized component of these systems. In order to take advantage of the latest available high-performance I/O infrastructure, to ensure reliability and backwards compatibility of data files, and to help unify the data structures used in LQCD codes, we have incorporated parallel HDF5 I/O into the SciDAC supported USQCD software stack. Here we present the design and implementation of this I/O framework. The “out-of-the-box” HDF5 implementation outperforms optimized QIO at the 10-20% level, with room for significant improvement with dataset chunking.